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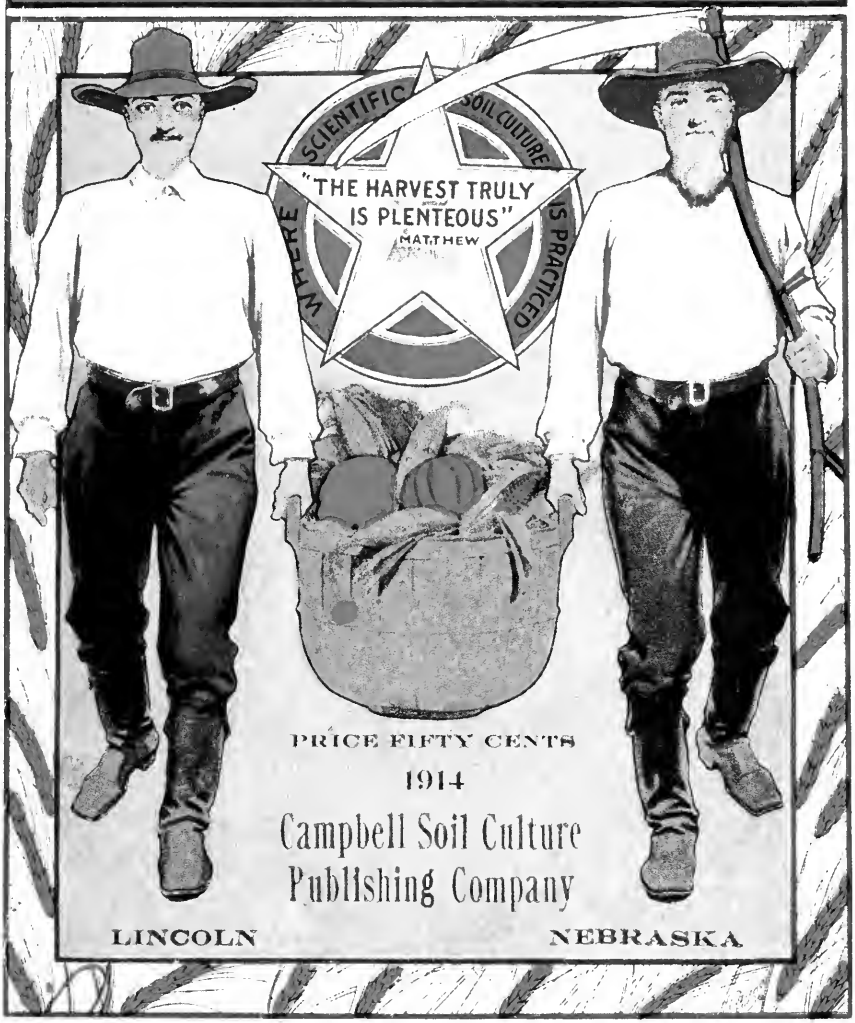

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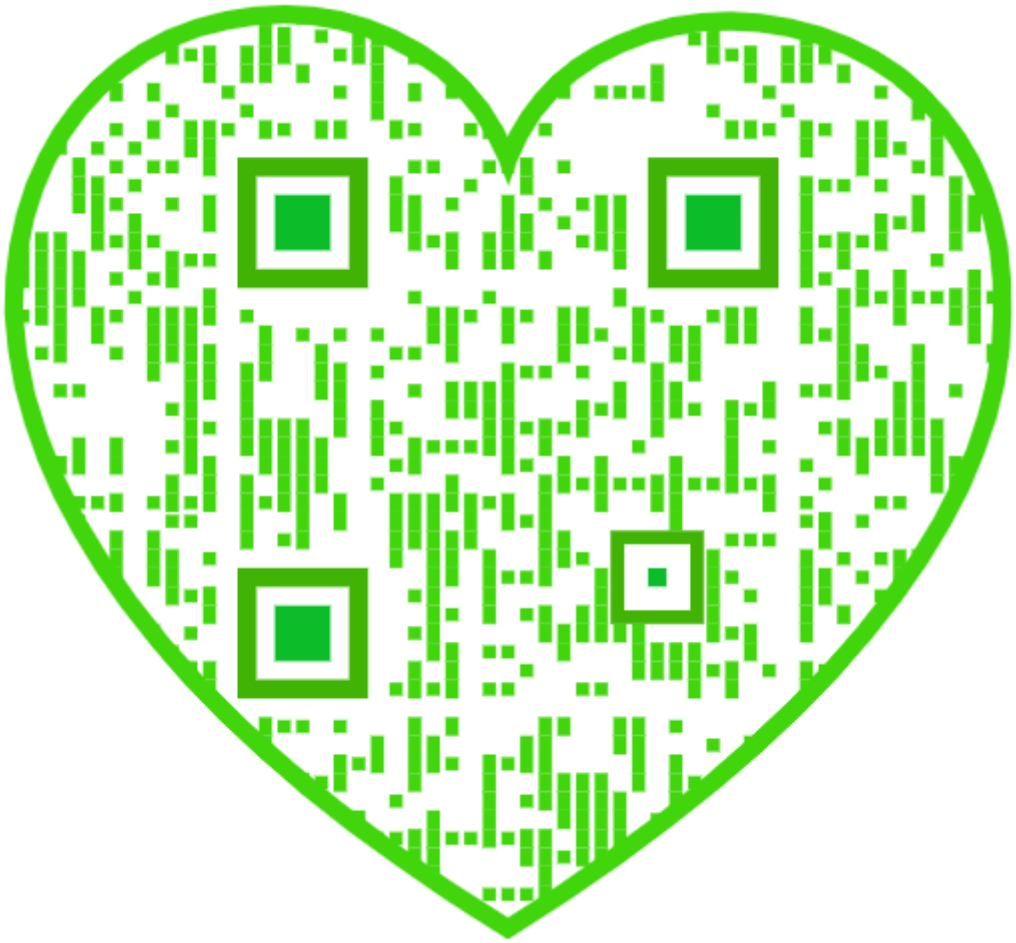

Scientific Soil Culture Series

RICHARD A. HASTE, Editor

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Campbell Soil Culture Publishing Co.

Lincoln, Nebraska

HARDY W. CAMPBELL

Soil Culture Primer

A plain and practical discussion of the relation of plants to the soil and the principles of growth; the laws governing the movement of water in the soil and its evaporation from the surface, and the principles of the conservation of soil moisture by cultivation, together with a full description of the practice of scientific soil culture known as the Campbell System, for the use of students and practical farmers everywhere but especially in the semi-arid regions of the world

BY

HARDY W. CAMPBELL

Author of Campbell's Manual of Soil Culture

REVISED AND EDITED

BY

RICHARD A. HASTE

Editor of Campbell's Scientific Farmer

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1914

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INTRODUCTION

It is with great pleasure that we offer to the public the fourth edition of Campbell's first manual of soil culture. This little book, which was first published in 1905, has been read wherever the English language is spoken. Moreover, it has been translated into Russian, German, and Hungarian, and the principles of soil tillage here for the first time arranged into a logical system are now taught in the agricultural schools and colleges of every civilized nation on the globe. The Campbell system of soil tillage as outlined in this manual, has doubled the agricultural area of the world. It is the key that has unlocked the storehouse of the great plains country of North America. The appearance of this little volume marked the beginning of the great dry farming movement that has spread the knowledge of scientific soil culture to every quarter of the globe.

It is with great satisfaction, therefore, that we have rearranged the topics of the third edition, illuminating them with the light of experience gained in the last ten years, both in this and in foreign countries. Within the limits of this book we can present only the elementary principles involved in scientific soil tillage (a full exposition of scientific soil culture and crop growing being found in the 1914 edition of the large manual), but we trust it will serve as a guide-board pointing the way to better methods, larger yields, and happier homes.

It is not intended to lay down a code of imperative rules to govern the farmer in every act of soil tillage, but to present the fundamental principles governing the development of plant life, the movement of water in the soil, the release of potential fertility, and the effect of proper tillage on the quality and quantity of the crops. When these fundamental principles have been thoroughly mastered the labor necessary to aid the crop in its development and render agriculture profitable will become evident to any one who is able to trace out cause and effect.

The farmer who works by rule, not knowing the principles involved, will fail as often as he succeeds. With him farming is a game of dice. He has no idea what the next throw will turn up. But, knowing the principles, he uses his judgment and varies his action with the changing conditions. If the

soil is too wet it must be drained, but if on account of insufficient rainfall it is too dry, the moisture must be conserved by proper preparation of the seed and root beds, and after cultivation for the benefit of the plant. We have learned how much moisture is required to produce a pound of dry matter of the various field crops; we have also learned how to hold the rainfall in the soil. Crop growing in the semi-arid regions then becomes a problem of the application of our knowledge to the conditions that we find. We cannot grow crops without water. This water must be supplied by either natural rainfall or by artificial irrigation. If the precipitation in the form of rain and snow averages eighteen inches per annum, and the evaporation is not excessive, field crops can be produced if the proper means are employed to catch and hold this moisture in the soil. This has been demonstrated so many times that it is no longer questioned by the intelligent investigator.

If the methods laid down in this manual for the conservation of soil moisture are carefully followed by the farmers in the great semi-arid regions of the United States and Canada, where the annual precipitation averages more than fourteen inches, cereals and the ordinary fodder crops can be produced profitably, and with reasonable certainty.

The storage and conservation of soil moisture by the careful preparation and tillage of the soil is the basis of all fruitful production. We have all observed the improved condition of the winter wheat where, owing to some obstruction in the field, snow drifts have lodged. The old idea was that the snow drift had acted like a blanket to protect the wheat during the winter and that the larger stand and better yield on that particular spot was owing to this protection. This we now understand was an error. The improved stand of grain was due to the fact that the hard-packed snow melted slowly and the moisture percolated into the soil to a much greater depth than in the exposed portions of the field and was stored there as in a reservoir for the use of the growing crop, so that when the summer drouths came and the wheat in the general field was checked in its growth by a scarcity of moisture, the stored moisture beneath the snow drift supplied the roots and kept the plants vigorous and growing. The roots of the plants, growing on the spot where the snow had drifted, were supplied from the reservoir of moisture below, which had come down into the lower strata of the soil as the snow melted in the spring, and was now slowly raised to the roots of the plants by the force of capillarity.

Similar results are observed when spring crops are planted on soil which has been covered with snow drifts that have slowly melted in the spring, the water sinking into the soil. It follows from these simple observations that the greater amount of water we can store in the soil before planting the crop and during its growth, the greater will be the yield, providing we so cultivate the surface as to prevent evaporation and thus hold the moisture for the use of the plant.

Another feature of scientific soil tillage, next in importance to the conservation of moisture, is the physical condition of the root bed. This should be fine and firm, that it may hold the moisture necessary to a vigorous root growth, for without a strong root system no plant can resist the periodical drouths that are bound to come.

And right here let us impress upon the reader, if by chance he is interested in irrigation, that all the principles herein outlined, having reference to the physical condition of the soil, the conservation of water, and the relation they sustain to plant life, apply with equal force to crop growing under irrigation. Dry farming is only a name to distinguish farming under natural rainfall from farming under a ditch—the principles involved in both cases are the same.

With these considerations in mind we have tried in the following pages to give a clear and succinct statement of the principles involved in all operations of soil tillage, having for their object the production of crops in both the humid and semi-arid sections of the world. Naturally these exact methods are more essential for success in the arid and semi-arid sections where the conservation of moisture is the primal consideration and crops cannot be grown without them, but they also apply to the regions of plentiful rainfall where drainage is necessary and drouths are likely to come.

HOW TO USE THIS TEXT

Do not get the idea that you can read this manual and then put into immediate practice the principles of scientific soil culture. If you do, you will be disappointed. Our common law is based on the principles of equity, justice, and common sense. Yet the best lawyers must study for years before they are able to reason out the right from the mass of complicated evidence and conditions that come up with every new case. The physician gives years of study to the science of medicine and yet so complicated are the conditions that he is often puzzled to know just which principle to apply. The same is true of the application of the principles of soil tillage to the varied conditions that are constantly arising. No two sets of conditions are alike and the application of the basic principles must be a matter of judgment. The reader will find it necessary, therefore, to go over and over the contents of this little book until he has mastered the principles and is able to apply them with judgment to the conditions as he finds them.

The cook in the kitchen may fail the first time she uses a new recipe. She has followed the directions in the cook book but somehow the result is not satisfactory. She tries again with better results and a third time with success. Unconsciously she has used her judgment and modified the directions to suit the conditions. She has not only studied the cook book but she has studied the ingredients and noted the temperature of the oven and the hundred other little things that affect results in the kitchen.

When you have read this book once, read it again—study it as you would a text book in school. Note what is said and compare it with your own experience and what others have written and said. Get the principles in mind, and then see to it that you are able to reason from these principles to the conditions that you have to meet. If you know why wheat should be rolled or harrowed in the spring, you will be able to determine from the condition of your field whether it needs harrowing or rolling, and when. The essential thing is to so understand the soil in its relation to moisture and plant life as to be able to reason fully and accurately what the effect of certain conditions will be, just when and how certain work should be done, and what results may be reasonably expected.

CHAPTER 1

THE SEMI-ARID BELT

A line drawn from the western lobe of the Lake of the Woods to Galveston, Texas, along the ninety-fifth meridian, will divide the United States into two nearly equal sections, and will mark in a general way the dividing line between the wooded and the treeless regions. This line is not regular, in fact there is a neutral ground of interspersed prairie and woodland that occupies the immediate valley of the Mississippi and Missouri. The history of the settlement of this middle ground by the pioneers from the east is an old story. Being used to the timber of New England and the eastern middle states they clung to the woods and avoided the prairies of Illinois and Iowa, thinking that the soil was worthless because it would not grow trees. It took twenty years to overcome this prejudice and induce them to brave the unknown dangers of the rich prairies. It was about 1875, when, encouraged by their success with the prairies, the bolder pioneers crossed the ninety-eighth meridian and entered the great plains—the Great American Desert as the old geographers called it. By thousands they flocked into the Dakotas and Nebraska and Kansas. A few favorable years encouraged them. Someone said that the rainfall followed the plow and everyone was ready to believe it. For a number of years this theory seemed to be the true one, and then came the great drouths and the return tide set in. A few stayed, and with the aid of their cows and chickens held the fort during the years of drouth and famine until the return of the rains and the new tide of immigration. Like the pioneers of Iowa they are wealthy now. In the early nineties the tide was turned back again, only to be renewed five years later. Each time the frontier was pushed farther west—the desert receding before the increasing knowledge of the soil and its possibilities.

Up to 1894 little attention had been given to the new problems of the soil. Old methods, such as were used in Illinois and Iowa were employed and when failure followed it was laid to a lack of timely rainfall. The question of the conservation of the moisture by tillage had not occurred to them. Great schemes were put on foot to overcome the disasters of the drouth. The press drill and other special tools of soil culture were introduced to overcome the lack of rainfall. Summer fallow was tried without effect. The "rain-

maker'' came with boastful confidence in the power of explosives to produce rain, and failed.

Then someone said that the presence of trees would bring rain, so thousands of acres of trees were planted, with the encouragement of the government through the tree claim act, only to be withered by hot winds or slowly dried out by long summer drouths.

Agricultural colleges and experiment stations were established at various points in the semi-arid belt, but the problems were new and the experiments were directed toward finding drouth resistant crops rather than to finding ways and means to conserve and utilize the moisture that God was giving every year and which under the old methods was allowed to go to waste.

It was not until the conservation and storage of the natural rainfall in the soil began to be comprehended, that there was any real light thrown on the problems of the great semi-arid belt.

The experience of the writer in South Dakota in the eighties, suggested this solution which time has fully proved to be the only means of placing the semi-arid regions of the world in the agricultural columns where nature evidently intended it should be.

As we more fully comprehend the forces of nature we become the more convinced that there is a law of compensation; that if we only seek diligently and with an open mind we will discover that everything has its use. It is within the bounds of possibility that the one time American desert before many years will become the center of the greatest agricultural region of the world. It is to assist those who are trying to solve the problems of scientific soil tillage in the semi-arid regions of the world that the following pages embodying the experience of the last thirty years have been written and given to the world.

CHAPTER 2

PLANTS AND THEIR STRUCTURE

Plants Resemble Animals

In order to fully understand the principles of soil tillage it is necessary to know something about the structure and habits of plants and their relation to the soil. As this is but a primer and deals with first principles only we shall be brief, but we hope the reader will study the following carefully, because it is one of the essential links in the chain.

Plants resemble animals in both the structure and the functions of their essential organs. Animals eat, drink and breathe. So do plants. Deprive an animal of water, food or air, and it will die—so will the plant. They both require the same food elements, but of course in different form. They both start life from a division of cells and develop by a multiplication of cells. The chief outward difference is that plants are attached to the earth and animals move about freely. The plant, however, in compensation has an advantage over the animal in the fact that it can manufacture its food from the original elements of the earth, while the animal must have this food prepared by some outside agency.

The Miracle of Growth

This food factory in each plant is very interesting and as an understanding of it lies at the very base of scientific agriculture, we will try to learn how it is operated and under what conditions the best results are obtained. The value of a cultivated plant is measured by its ability to gather food from the soil and from this raw material manufacture grain or fruit.

To take dead forms and change them into living things, once would have been regarded as a miracle. But that miracle is being performed by millions of plants every hour of the day—all over the world. It is the miracle of growth. To help the plant in the performance of this wonder-miracle by intelligent cultivation is the duty of every farmer.

Origin of Life

We do not know what life is—we know only its manifestations. But we do know when things are alive and when they are dead. As a general rule, things that are alive grow. A quartz crystal, if kept from the weather, is the same yesterday, today and tomorrow. It is dead. But a living thing changes from day to day, or from year to year. It cannot remain the same—it has life.

Plants, from the microscopic *bacteria* that form the green scum of the stagnant pool, or the mould on stale bread, to the oak tree are all composed of cells—microscopic cells, the walls of which are composed of cellulose—a non-living substance, but within is a jelly-like matter called protoplasm.

Chromatin

Within these protoplasmic cells is a microscopic body in the shape of a sphere called the nucleus—this nucleus contains a substance called *chromatin*. This is as near the origin of life as science has been able to get. The protoplasmic cells have the power to build new cells from the lifeless material about them. Protoplasm has the power of independent movement, and is able through some chemical action, to tear down and build up cell structures. As long as these chemical processes go on, protoplasm is alive—when they cease, it is dead.

Protoplasm has the power of increasing, or growing, by a division of its cells. When this takes place the nucleus divides, pulling apart, forming two separate and complete cells, which in their turn divide. This is the lowest form of growth. The entire structure of plants, from the roots to the leaves and flowers, is but a repetition of this cell formation. A tree grows simply by adding additional cells to its stem and branches.

Elements Essential to Plant Growth

The elements that are used in the plant laboratory for the manufacture of its food are very many. But those regarded as essential to plant growth are oxygen, nitrogen, hydrogen, potassium, calcium, magnesium, chlorine, phosphorus, iron and sulphur. With the exception of oxygen all these elements are absorbed by the plant in some kind of chemical compound, such as carbonic acid, nitrates, carbonates, sulphates and water. Now this may sound very technical and difficult to remember, but it is all very simple.

The chief constituent of all plant substances is carbon. It forms fully one-half of the total weight of dry vegetable matter. The great coal deposits of the world are mostly carbon. Charcoal is the wood of a tree with the other elements driven off by heat, leaving the carbon. And this carbon is obtained almost wholly from the air, while in the form of carbonic acid gas—a combination of carbon and oxygen. We shall see later that this gas laden with its carbon, is taken into the laboratory of the plant through the leaves. A small amount of carbon, however, is brought in through the roots in water solution.

Roots as Food Gatherers

The other elements are found free in the soil or in various combinations, and it is the business of the roots to go out and gather them in. But the plant can not use them nor transport them unless they are dissolved in water. Water, then is as essential to the life and growth of a plant as is food—in fact it is the only means by which food can be taken into or utilized by the plant, and this water can reach the interior of the plant only through the roots.

The roots, therefore, are not only the food providers of the plant, but they are the water carriers as well. They are the field men that go out and gather in the raw material which is needed by the plant food factory. They not only gather and select it, but they build little canals and supply water transportation for whatever is needed. The manner in which the roots do these things is most interesting and most important, and the man who does not know something of the functions and habits of roots—how they do their work—is not prepared to intelligently cultivate his crops.

Structure and Functions

There is no particular difference between the structure of roots and the structure of branches and leaves. They are all formed by a multiplication of cells and they grow by adding cell after cell to the tips. From the main root a number of small branches are put out which give rise to other branches, pushing their way between the soil particles, seeking for air and moisture containing the food desired by the parent plant. Covering the smallest rootlets are millions of microscopic hairs—little cellular filaments, which have the power to absorb from the soil-particles the moisture that holds in solution the various chemical elements wanted.

Soil Moisture

Soil moisture is of three kinds—free, capillary and hygroscopic. The free water is that which percolates, or runs between the particles of soil causing it to become wet and slushy. This is the water that disappears when the soil is well drained. Capillary moisture is that which remains in the soil and gives it the feeling of dampness. Capillary moisture moves freely among the soil particles and always in the direction of the dryer portions. When the surface becomes dry by evaporation, the capillary water moves up from below to equalize the water content of the soil. Capillary moisture is held by the attraction of the soil-particles for the molecules

of water. It is the capillary water that the plant mainly depends on for its growth.

In the air around each microscopic particle of soil is a small amount of moisture held so firmly in place that it is influenced neither by gravity nor by capillarity. This is called hygroscopic moisture and is present in all soils, but it is of no immediate use to the plant.

Office of Root Hairs

Now coming back to the thread-like filaments called root hairs, we find that they attach themselves to the soil particles and absorb soil moisture into their cells. When the film about one soil-particle is exhausted moisture flows in from another particle under a law of equilibrium. This moisture charged with the elements of plant food is passed along the cells of the root hairs to the larger roots and so on to the stem of the plant.

The growing rootlets, and root hairs are absorbent for

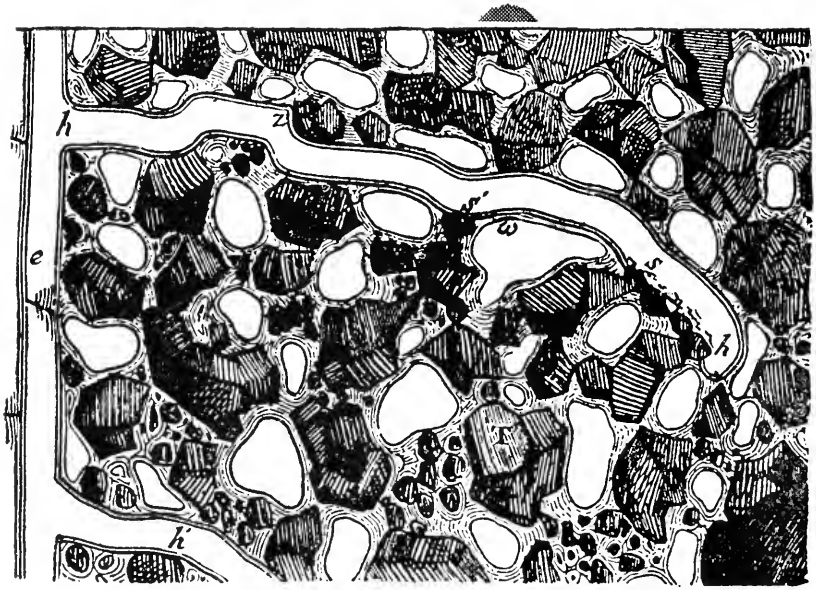


FIG. I

Root Hairs and Soil Particles Greatly Magnified. The Dark Spaces Represent Soil Particles, the Shaded Portion Moisture, and the Light Spots Air

water with mineral matter in solution only at their tips for probably not more than one-tenth of an inch. As they grow the body of the root, back from the tip, becomes covered with a layer of cork cells, full of air, which prevents the entrance of water. So it will be seen that the active part of the root today becomes inactive tomorrow, and that fresh mouths are continuously opening eager for food. This is why it is useless to water a tree or a plant close to its base—the feeding roots are apt to be far distant.

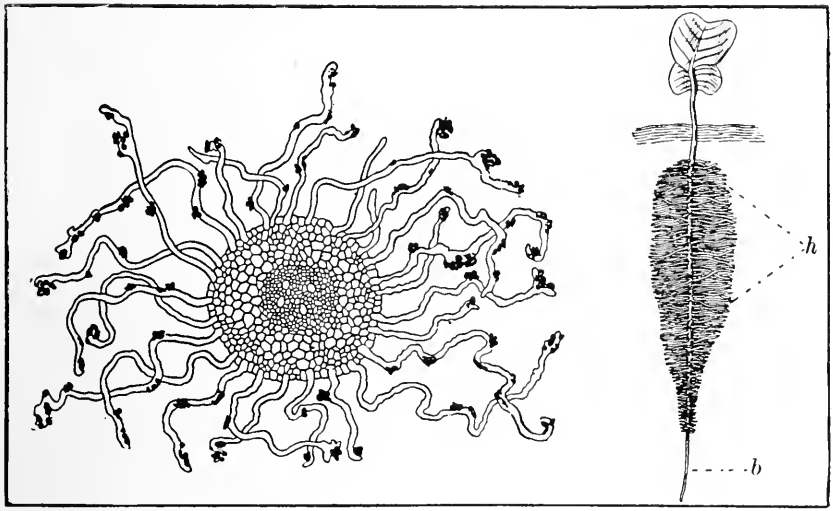


FIG. 11

Cross Section of a Root Magnified Showing Root Hairs Attached to Particles of Soil. h—Root Hairs on a Primary Root

You see how important it is to know the root habits of plants that you are cultivating. If you are irrigating, you will know where the plant wants water, and if you are cultivating you may avoid disturbing the food-gatherers as they are wandering around beneath the surface.

Air in Soil

As the process of root growing is nothing more than the adding and breaking up of cells of protoplasm, they must have access to the oxygen of the air in order to complete the chemical change necessary to this growth and decay. If the soil has not a certain amount of air in it, root growth will stop. That

is why plants are said to drown out and fruit trees are said to get *wet feet.* The ground becomes so saturated with water, that all air is excluded, and the roots suffocate for want of oxygen. This fact is very closely related with tillage. You will find hereafter, that a crust is liable to form under the mulch in well-tilled corn fields, completely shutting out the air from the roots, causing the corn to curl and show all the signs of a lack of water, although there is plenty of moisture in the soil below the crust. The air has been shut off by the formation of the crust and the roots stop work.

Air and Its Importance in the Soil

Air in the soil has not received the attention and study that its importance demands.

Because we have seen it constantly demonstrated we know the necessity of water in the soil for plant growth, but it is not so easy to comprehend the material value to the plant of air in the soil. We cannot see its effect in anything like as broad a sense as we do the water, yet this presence in proper quantities in the soil and about the roots of the plants is just as vital to its life, health and growth as water.

Water without air and its component parts is worthless; air without water and its component parts is equally valueless to the growth and development of all farm crops.

How many times have we seen a field of wheat, corn or oats, possibly half-grown, and noted that in some depression the crop was ranker in growth and also a darker green. If a rain of considerable magnitude comes and the depression fills with water and remains there for some days, the plants that seemed to have the advantage before the rain now begin to lose their healthy green; if the water remains long enough over the surface they turn yellow, then brown, and finally die. This is because of a lack of air at the roots.

Osmosis

All plants have the power of taking in through the cells of their root tips and their root hairs, the substances necessary to their growth. This process of absorbing soil moisture is called *osmosis.* Just why the absorbent cells will take in certain substances and reject others is not known. Goff explains it by citing the law of diffusion, and Widtsoe explains it substantially as follows: When the solution of water within the plant is stronger than that of the soil water the effort to equalize it causes the solution to flow from the soil to the plant. But whenever the solution in the soil be-

comes stronger than that of the plant, the process not only ceases, but is reversed. This is why soils heavily impregnated with alkali become fatal to plant life.

The Leaves

Leaves are popularly believed to be the lungs of the plant. While this is in a sense true, they are more like the digestive organs, for they are in every sense the food factories of the plant. It is here that the original elements taken from the soil and from the air are broken up and recombined into forms that may be turned into tissue.

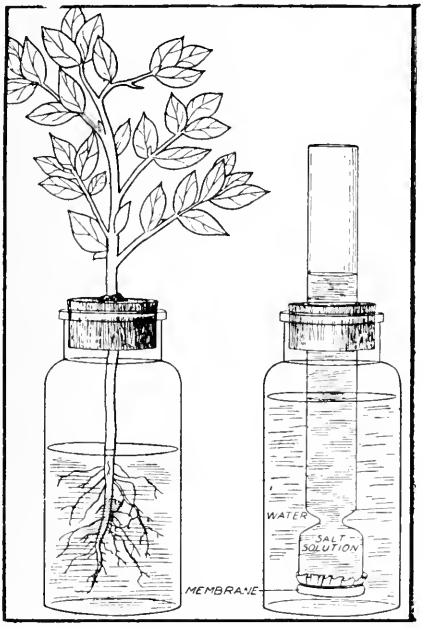


FIG. III

A Common Experiment Showing the Similarity of the Action of Osmosis in Plants and a Salt Solution Through a Membrane

Chlorophyll

When a leaf is exposed to light it turns green. This green color is due to a substance known as chlorophyll. This chlorophyll is produced in some mysterious way by the action of sunlight on protoplasm. That it is produced by the immediate action of sunlight is proven by the fact that it disappears

whenever the plant or the leaf is removed from the light of the sun. The bleaching of celery is simply the removal of chlorophyll. The pale and sickly color of potato sprouts in the cellar is due to the absence of chlorophyll.

Chlorophyll forms in minute globules which adhere to the cell walls. They are more numerous near the upper surface of the leaf where the sunlight is stronger. The function of chlorophyll, or the work that it performs in the food factory must be borne in mind in all our study of plant life, for without it the plant has no power of assimilation—no power to form plant food from the raw ingredients of the soil and air. Chlorophyll and sunlight are the two magicians that take the dead particles of earth and transform them into food for living cells.

What Happens in the Leaf

If you heat starch it will separate into water and carbon dioxide. This suggests that it can be *formed* by the union of water and carbon dioxide, and this is just what is brought about by the action of sunlight in the leaf. The leaf absorbs carbon dioxide from the air and by utilizing the energy of the sun to break up the combination between the carbon and oxygen, it liberates the carbon, which immediately unites with the water which has been drawn up from the roots, forming starch. The oxygen not being needed, is allowed to pass off into the air. The leaf, therefore, becomes a starch factory and starch is the original food of all plants. In order to run this factory to its greatest capacity, the leaf exposes its greatest surface to the sun's rays, but in so doing it runs the risk of losing too much water by evaporation.

Stomata or Leaf Pores

An arrangement, therefore, is made for numerous openings mostly on the under side of the leaf, called stomata, through which the oxygen that has been liberated by the decomposition of the carbon dioxide and water is allowed to escape. When there is an abundance of moisture in the ground at the disposal of the plant, these little valves are open, allowing a large per cent of moisture to escape, but when the moisture in the ground is limited these valves automatically close, thus preventing unnecessary escapement of moisture. This process of absorption by the roots and evaporation from the leaves is called *transpiration*, and much depends upon a correct understanding of the principles governing it and the means by which it may be controlled, for like the respiration of a human

being the transpiration of the plant indicates very clearly its physical condition.

The action of these little guard cells in the stomata is very curious. They close at night and mostly on cloudy days. This makes it possible to fumigate orchards with poisonous vapors at night which would be fatal to the plants if done in the day time. Also it will be observed that these openings are carefully guarded by being mostly on the under side of the leaf and surrounded by waterproof material. This is why a leaf glistens with a multitude of little points when immersed in water.

The exact chemical process which takes place in the leaf cells is described in the Encyclopedia of American Agriculture as follows:

Carbon dioxide passes through the stomata, comes thoroughly into contact with the leaf cells which are sufficiently separated from each other to allow it to pass unavoidably between them. The great absorptive surface which they expose is kept continuously moist and is thus able to absorb with great rapidity much as the moisture along the surface absorbs the oxygen. The exposed carbon dioxide passes into the cell and comes into contact with the green chlorophyll grains. The chlorophyll in these portions is divided into very minute drops—thus giving it an enormous absorptive surface. At the same time that it takes up carbon dioxide it absorbs sunlight and with energy thus received it decomposes the carbon dioxide, causing the carbon to unite with the water, thus forming sugar. This may be illustrated by the equation

$$6CO_2 + 6H_2O = C_6H_{12}O_6 + 6O_2$$

Carbon dioxide Water Grape Sugar Oxygen.

CHAPTER 3

SOIL MOISTURE

Movement of Soil Moisture

Water is the life blood of plants. Nothing will grow or even germinate without moisture. It is very clear then that on the presence of moisture and its movement in the soil depends not only the life of the plant but the yield of all farm crops. You see how important it is for the farmer to understand how this water moves in the soil and how best to store it for the use of the plant.

We learned in the previous chapter that soil moisture was of three kinds—gravitational, capillary and hygroscopic; that gravitational water is the free water of the soil—the water that seeps down through the soil and drains off into the streams and lakes—that capillary water is that which surrounds each particle of soil and is held there by the force of capillary attraction; that hygroscopic water is that which is to be found in the air of the soil, filling the spaces between the soil particles. It is important to know here that neither the gravitational water nor the hygroscopic water is of any use to field crops directly. It is only the capillary water in contact with the roots that furnishes the plant with food. There are some exceptions to this rule but it is sufficiently accurate to answer our present purpose.

Capillarity in the Soil

We all know that if we put one end of a towel in a bowl of water the water somehow will find its way to the other end of the towel. We know that a sponge will take up or absorb water from a dish as soon as one part of it touches the surface. We know that the oil in a lamp, in some way, climbs up the wick to the flame where it is burned. We know, too, that blotting paper will absorb ink. In all these familiar cases we have learned that the property of the towel and the sponge to take up water and the lamp wick to absorb oil and the blotting paper to take up ink is called capillary attraction. Now let us see how this thing is done. Let us take a number of glass tubes of different diameters, open at both ends, and stand them in a pan of water (Figure 4). We notice at once that some of the water begins to rise in the tubes above the level of the water in the pan. We notice further that it rises to different heights—the smaller the tube the higher it climbs. We notice also that the surface of the water in the tubes is concave. This is very important.

How does all this apply to the movement of soil moisture? Is the soil made up of tubes? No, not exactly, although there may be many root paths that do act as tiny capillary tubes for the transportation of moisture. But the soil is made up of minute grains with spaces between them. It is through these spaces that capillary action takes place. To illustrate to the eye the combined action of capillarity and surface tension in the soil, take a number of spheres (Fig. 5), dip them in oil and suspend them free from contact except with one another. The oil will not all run off. Some of it will gather at the bottom of the lower spheres, but a film will remain around each, being thicker where two spheres touch or nearly touch. These films are kept in place by the action of both surface tension and capillarity.

How water moves in the soil, adjusting itself among the soil grains, is illustrated by Figure 6, which represents three soil grains surrounded by a film of water of unequal thickness. This condition could not exist for long in a state of nature,

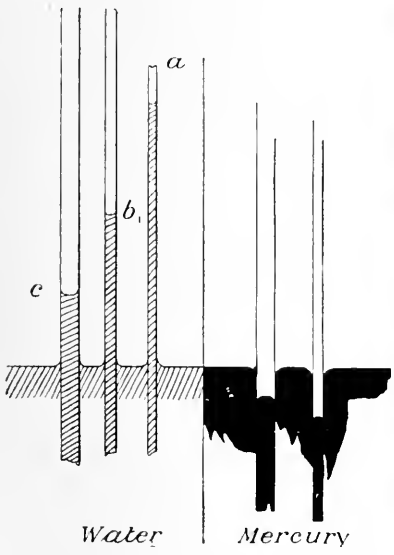


FIG. IV

Capillary Action in Water and Mercury

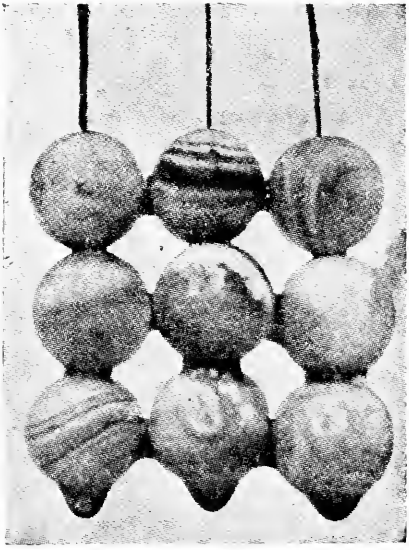


FIG. V

Illustrates Liquid Films Around Soil Particles

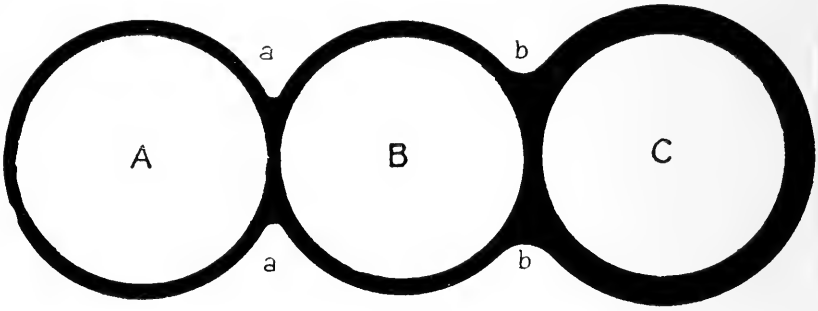


FIG. VI

because the whole film acts as if it were enclosed by an elastic band. The liquid would be forced toward the grain where the film is thinner and toward the film of greatest curvature. That is how moisture moves in the soil. If the three particles had all the same thickness of film and some of the moisture were removed from one by the plant roots, withdrawing some of the moisture, there is a suction created—a pulling and a pushing—which forces the water even against gravity, toward the place where the moisture has been removed. A growing root absorbing moisture, therefore, causes the moisture content of the soil in its immediate neighborhood to move in its direction. This movement of water in the soil depends largely on the texture of the soil itself—depends upon whether it is coarse or fine, the amount of moisture that it contains, and the grain or nap of the soil strata.

The Run-off

In the arid and semi-arid regions of the world (and these constitute one-half of the earth's surface), where the natural rainfall is depended on for the growth of agricultural crops, only about twenty-five per cent of the precipitation enters the ground and becomes soil water—the rest is lost in the run-off or is dissipated by evaporation. The dry, hard surface of the semi-arid plains, with their coat of buffalo grass, sheds water like a thatched roof. The dry soil beneath repulses the moisture it needs so much, and nothing but a slow, drizzling rain of several days duration will do much permanent good to the bare uncultivated fields. Many good, dashing rains that register two inches in the pluviometer fail utterly to penetrate the unplowed surface more than half an inch, affording no relief to the thirsting grass roots below.

It is of vital importance, therefore, to prepare the surface of the ground to receive and absorb the moisture as it falls.

As much depends upon preventing the run-off as in conserving the water after it has been caught in the soil. The two great objects are, first to get the water into the soil, and second to hold it there for the use of the plant.

To prepare the soil to take in the water as it falls as rain or snow, is then the first object of the farmer, no matter where he may be located. This means loosening up the surface—increasing the pore space between the grains of the upper layer of soil. This is best done by plowing or harrowing. Whether a mould-board or disk plow should be used depends on the kind and the physical condition of the soil. The plowing should be deep enough to form a soil reservoir to catch and hold the average rainfall and not so deep as to prevent this same water returning by capillarity to the root-bed of the plants when needed.

Loss of Soil Moisture

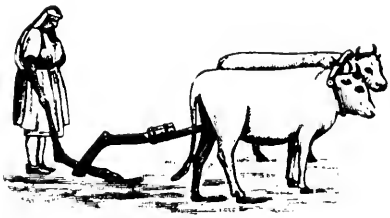
Having caught the water, the next thing is to hold it—and hold it where you want it. But soil moisture is much easier to catch than it is to hold. In this respect it is like money—many seem able to get it, but few are able to hold onto it permanently.

Soil water is lost in four ways: First, by *percolation;* this will happen in very loose soils underlaid with a subsoil of coarse sand, or gravel, through which the water drains; second, *evaporation* from the surface; third, by passing into and through a growth of weeds; and fourth, by *transpiration* through a growing crop. This last is the way we want it to go, and every effort should be made to compel it to take this route, and none other. Owing to some very recent discoveries the subject of transpiration has become the most important factor in the solution of the many difficult problems of crop growth and crop yields. It will be discussed later under the proper head. For the present we will see how water is lost from the soil by evaporation, and to what extent it can be prevented.

By Evaporation

While the soil is filled with air which, when the soil is loose in texture, or kept in good tilth, is in constant circulation, very little moisture is lost that way, for the reason that this soil atmosphere is usually near the point of saturation. But this is not so with the atmosphere above the surface. It is seldom at the point of saturation, especially in the arid and semi-arid regions. It is always thirsty. And when this thirst

is aggravated by the heat of the summer sun, and forever renewed by the constant winds, every bit of moisture that shows its head above the surface of the ground is lapped up—absorbed and carried away. The great problem then is to keep the soil water from coming to the surface. The wind and the sun act on the moisture in the soil just as the flame acts on the oil in the wick of the lamp. As rapidly as the oil is consumed by the flame, or the moisture evaporated by the sun and wind, capillarity brings more up from below to take its place. When we wish to stop this evaporation of oil in the lamp we blow out the flame; but we can't blow out the sun nor stop the wind. We must resort to some other means to check this capillary action. We must break the connection. We can do it by cutting the wick in the lamp—we do it in the soil by forming a mulch over the surface through which capillarity will not act. The sun may now shine ever so warm and the hot winds blow—the soil moisture is securely bottled up and the cork that holds it in is the surface mulch.



PERSIAN PLOW.

CHAPTER 4

THE OBJECTS OF CULTIVATION

Knowing something of the structure and habits of plants and also of the movement of moisture in the soil and its relation to the growth of the plant we are in a position to understand the objects of cultivation and to comprehend the principles involved in the various processes known collectively as soil tillage.

The soil in its natural condition produces abundantly, especially where there is moisture, heat, and sunshine; then why cultivate the ground—why plow and harrow? Why not let nature take her course unmolested? Let us look into this. The objects to be secured by cultivation of the soil may be arranged under seven heads.

To Destroy Plant Growth

Paradoxical as it may seem, the first object of plowing is to destroy plants. If the plant growth that covers the virgin soil is too large for the plow, it is cut down and removed or burned, in order to give the plow a chance to operate. If the growth is short, forming a sod, it is destroyed by turning it under, thus exposing the roots to the action of the sun and weather. This is the work of the sod breaker.

Conservation of Moisture

The next object in order of importance is the conservation of moisture. This applies to all countries, no matter what the rainfall, but more especially to the semi-arid districts where the annual precipitation is supposed to be short and uncertain. Plowing, by rendering the surface uneven, prevents the run-off and forms a temporary reservoir for the storing of excessive rainfall until it has time to seep into the subsoil or be taken up by capillarity.

To Facilitate Drainage

In sections of the country where the rainfall is abundant and the soil is likely to become saturated, plowing, especially deep plowing, assists drainage by allowing the water to seep away more rapidly than it would through an unplowed surface and a compact subsoil. Poorly drained fields are plowed in "lands", the dead furrows between the lands serving as open ditches to carry off the surplus surface water.

To Prevent Evaporation

Turning over the furrow slice breaks the capillary connection with the subsoil and prevents the stored water in the subsoil rising beyond that point and being evaporated by the air. The plowed soil acts as a mulch to protect the moisture below. Don't get this confused with the soil mulch that is maintained by cultivation after plowing, for the purposes are entirely different. In actual practice, plowing, itself, is not relied upon as a mulch, to hold the moisture, but on the contrary, every effort is made to reestablish capillarity between the furrow slice and the subsoil by the use of a subsurface packer, relying on a surface mulch to prevent evaporation.

To Destroy Weeds

As the first object of the prairie breaker is to destroy the sod, so one object to be attained by plowing old land is to destroy the weeds. This is accomplished in two ways—first, by turning a half-grown weed under at a time that it will easily rot, and, second, by burying weed seeds so deep that they will not come up. As a general rule, weeds are surface growers, and when buried deeply fail to reach the surface.

To Aerate the Soil

One of the principle effects of plowing is soil ventilation. It opens the soil up so the air can better circulate through it. This, as we have seen, is of vital importance to the plant. It not only encourages nitrification, but the presence of an abundance of atmospheric air in conjunction with moisture oxidizes or rots the organic matter. By this same process of oxidation the soil is purified of plant excreta, and other toxic matter. Plowing is the first step in the process of plant house cleaning.

To Liberate Plant Food

Now we come to the last and most important object of plowing—the liberation of plant food. By pulverizing the soil, we expose its particles to the action of the elements. The soil moisture forms a thin film about each grain and begins the attack. Acids formed by decaying vegetation aid in the unlocking of the treasure chest, while the oxygen of the air, aided by the heat of the sun, completes the work. The plant food found in the soil is not in shape to be used by the plant—it must be broken up and reformed chemically to be available. Moisture, heat and air are the agencies that bring about this change, and the finer the soil is pulverized, the more readily can these agencies do their work. Under most conditions the plow that best pulverizes the soil is the best plow.

When Shall We Plow?

The question that is more frequently asked than any other regarding the cultivation of the soil is, "When shall we plow?" It is much easier to say, when we shall *not* plow. Here, again, it is very difficult to lay down a hard and fast rule. But this much we do know: never plow ground when it is *dry*, and never plow ground when it is *wet*. By observing these two admonitions, the farmer cannot go far wrong. To plow heavy soil when dry is a positive injury to the soil and a needless waste of power. It is always better to wait until the upper layer is sufficiently moist to turn over easily and crumble readily. This is evident to anyone who will think a moment—the first object of tillage is to place the soil in such a condition that the plant rootlets can get at the food that is contained in the capillary solution about the soil grains. If the plow throws up clods only, you have made no advance toward the end to be attained. These clods will have to be broken up or dissolved by the ordinary process of weathering before the plant can get a foothold. Plowing, therefore, should be done when the soil is in the best condition to respond to the pulverizing effect of the mouldboard. To get the soil into a proper relation with the water and air content it should be fined—pulverized, and this cannot be done by turning a hard crusted top to the bottom and then leaving it there with no further work until the field is all plowed.

The Best Soil Condition

Every plowman has noticed when plowing certain soils that are neither too wet nor too dry, just moist, how easily the plow is drawn and how readily the soil grains separate, as the furrow slice breaks over and crumbles into the furrow. The newly turned soil seems almost alive. This is the condition when the free water from either irrigation or from showers has percolated through the upper soil, leaving the capillary water surrounding each particle in the form of a thin film and the interspaces filled with air. And this condition of soil moisture may be maintained almost indefinitely if no weeds are allowed to grow and about two inches of the surface is kept loose and dry by cultivation. As plowing is done for the purpose of preparing a seed and root bed and as it is practically the first step in this line of preparation, it should be done only under the above conditions, and in the semi-arid sections as much in advance of the seed time as possible,

providing always that the proper kind and amount of tillage can be given it and at the right time.

Fall Plowing

Is fall or spring plowing to be preferred? This is another question the answer to which depends almost entirely upon local conditions of both soil and climate. In sections where the rainfall is deficient, fall plowing puts the soil in condition to absorb and retain the winter snow and the spring rains. In the humid sections where the rainfall is often excessive in the spring, delaying the spring work, fall plowing assists surface drainage, thus allowing the upper soil to dry out and be warmed up by the sun. Under these conditions, fall plowing, if done well, often advances the planting season from ten to fifteen days.

Another advantage from fall plowing is the liberation of plant food by weathering. The action of the atmosphere and the freezing and thawing process in the late fall and early spring have a tendency to pulverize whatever clods are left, giving the subsequent moisture free access to the soil grains. This is particularly true of clay lands, which in the sections of ample rainfall may be thrown up in ridges in the fall to facilitate, not only the process of weathering, but that of spring drainage. Under semi-arid conditions the problem is somewhat different. There, fall plowing may be practiced with advantage if the ground is in proper condition as to moisture in the fall to plow. The land, if plowed, is left in a better condition to absorb moisture, and, as a general rule, if a subsurface packer be not available at the time of the plowing, the root bed will have time to become firmed by the action of the elements. By this, we do not mean that you can afford to omit to pack the subsurface, for, if the fall and spring rains do not come to do your packing for you, you will be likely to fail—better not take the risk, but follow your fall plowing with a packer.

Spring Plowing

We are always in a hurry in the spring. So many things are to be done—things that must be done, that whatever work that can be done in the fall and well done, should be done. One great advantage from fall plowing is that so much of the work is done and out of the way. In the south, where the seasons are long, fall plowing is not an economical necessity, although there may be a number of advantages to be derived from it. Spring plowing, however, is the practice in the south

and may begin any time the soil is found to be in condition. In the north the case is different. Time is the main factor of the problem north of Mason and Dixon's line. The farmer must get into the field as soon as the ground will permit him to do so. He often has to begin before the ground is sufficiently dry to do the best work. In the northwest the furrow often exposes the frost in the ground, plowing having begun as soon as a three inch furrow can be cut. And this is not detrimental to the soil, especially if freezing nights follow warm. sunny days. The plowing, with the succeeding frosts and sunshine tends to dry and warm the soil for the seed, hastening germination and thus lengthening the growing season.

Subpack Spring Plowing

Spring plowing should always be followed by the subsurface packer. This should be done, no matter what you are

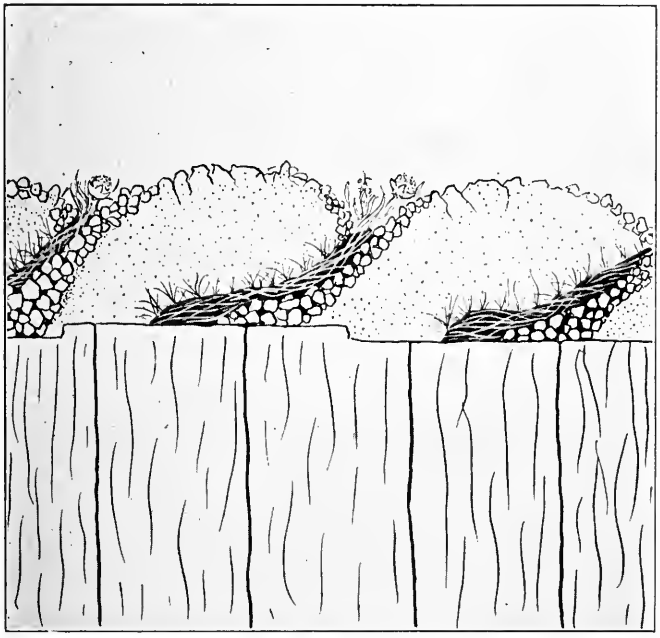


FIG. VII

Condition of the Soil as Left by the Plow

to plant. The reason is this—plowing, cutting and turning the furrow slice has broken capillary connection with the subsoil. Under each furrow are open spaces—air spaces—often filled with stubble, manure or other trash that has been turned under by the plow. This will prevent the plowed portion of the soil from settling and becoming sufficiently firm to form a root bed. Not only that, but these spaces will prevent moisture from rising from the subsoil to the roots of the plant should the moisture in the upper or plowed portion become exhausted. It is clear, then, that in order to get the best results from your soil plowed in the spring, you must obliterate these air spaces and restore capillary connection, and the only implement that will do it is—a subsurface packer. Many a promising crop has been lost during a drouth when there was abundant moisture in the subsoil just below the furrow slice.

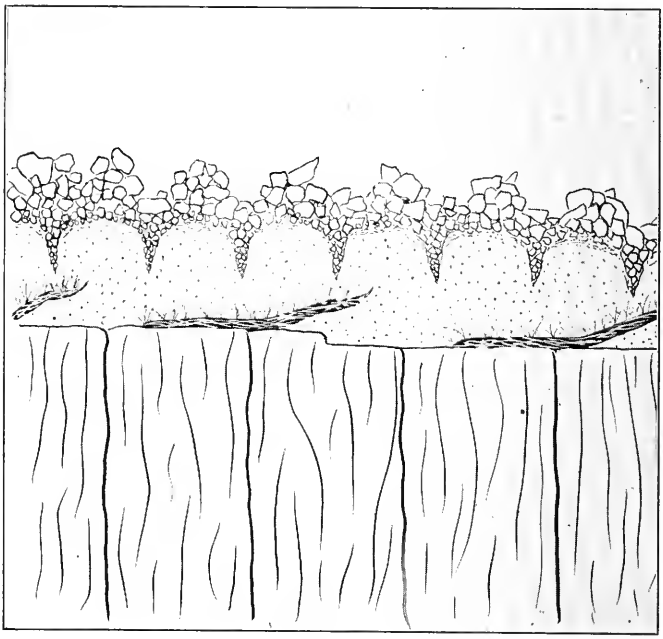


FIG. VIII

Condition of Soil as Left by the Subsurface Packer

Preparing for the Plow

In order to secure the best results from plowing, in many cases, the land should be prepared beforehand. The stumps and stones not only should be removed, but corn stalks and other trash that litter the surface should be reduced in some way so that it will be readily and completely turned under by the mouldboard. Some farmers plan to leave stubble and stalks exposed so as to prevent the land from blowing, but there are other and better ways to accomplish this end. At this point it might be well to mention the practice in some localities of burning stubble. This should never be done, as the incorporation of the stubble with the soil improves the physical condition by lightening the soil and adding to the humus content.

Disk Before Plowing

Where small grains are grown, the disk should follow the harvester. Not a week after, or a day after, but immediately. Why should this be done? First—it crushes the stubble and mixes it with the soil; second—it forms a loose mulch, which prevents evaporation from the exposed surface; third—it covers whatever weed seeds that have ripened and causes them to germinate and grow in time to be turned under by the fall plowing, or killed by the autumn frosts. But an additional benefit, and one that must be taken into account when considering fall plowing, is that this disking by checking surface evaporation brings up the moisture from the subsoil to the under side of the mulch, producing an ideal condition for plowing.

This applies not only to fall but also to spring plowing. No matter what your crop is going to be and no matter where your land is, if you are going to spring plow, get into the field with a disk as soon as possible. If it is inclined to be a little wet, the disking will help to dry it out and will assist to reduce the stalks and stubble to a condition where they will readily turn under. But better still, the disking will check evaporation, and in the west, where the soil is fine, prevent to a large degree that curse of all fine western soils—blowing.

When Not to Plow

Plowing is a good thing, but we may sometimes have too much of a good thing. There are times when a field should not be plowed—better results will be obtained without it. The reasons for this are interesting and should be always

kept in mind. Some crops are deep feeders, while others feed near the surface. The cereals, for instance, are shallow feeders, while alfalfa, potatoes, and cultivated crops generally are deep feeders. Now you can readily see that a crop that feeds within a few inches of the surface will exhaust the fertility within reach of its root system only, leaving the lower stratum of the soil still stocked with plant food. If the next crop is to be a shallow feeder it is the proper thing to plow this soil reasonably deep, turn under the exhausted surface and bring up the rich subsurface within reach of the roots of the plants. But if the next crop is to be a deep feeder, it may be well to simply disk the surface to get a good seed bed, providing the root bed appears to be in the proper physical condition. To illustrate this with concrete examples, we will take a potato field and follow with oats or wheat without plowing. The potato is a deep feeder and the constant cultivation given the surface has liberated a stock of plant food that has not been used, but lies waiting for a surface feeder. A corn field may be disked, then sown to oats or wheat and better results obtained than would have resulted from a thorough plowing.

Deep Plowing

The subject of the depth of plowing is one on which the "doctors" fail most woefully to agree. Certain "agriculturists" advocate deep plowing—plowing from twelve to fourteen inches, especially in the semi-arid west. The reason they give for favoring this deep tillage is that it will afford an extensive reservoir for the storage of moisture. This, however, is only a half truth and like many other half truths, is dangerous. Stirring the soil and rendering it loose to a depth of from twelve to sixteen inches, will doubtless put it in condition to prevent the "run-off" in case of heavy showers; but, further than this, the deep tillage fad for the semi-arid section has no virtue. The contention that it furnishes an easy root bed is fallacious; so, too, is the contention that the soil will thus hold a greater amount of water. These deep plowing advocates seem to lose sight of the distinction between free soil water and capillary water. While the deeply plowed land will allow a large amount of free water to percolate through it, down to the subsoil, it is incapable of holding and delivering to the plant as much moisture as will firm a soil. It is capillary water and not gravitational water that the plant must depend upon. That is why the root bed must be firm and not loose.

Where and When to Plow Deep

Deep plowing has its place, but it cannot be applied universally. Here again it is a question of soil and climate conditions. If three inches is good, it does not follow that six inches is better. To regulate his plowing to the best advantage, the farmer must know his soils, and must be familiar with the feeding habits of the crops he has been growing and wants to grow. He must also know the crooks and turns of the climate under which he proposes to operate. To advise one man to plow deep because another man had secured good results from deep plowing is like giving tooth-ache medicine to a man suffering from indigestion.

Heavy soils, especially the clays that have been plowed from four to six inches deep for a number of years, will be benefited by a deep plowing—a plowing that will turn up the soil from a depth of eight to ten inches. This soil will be benefited by a loosening up and a thorough ventilation. And lighter soils that solidify readily will stand deep tillage, providing a subsurface packer is used to firm the root bed if a crop is to be planted soon. Then again, a field that has been planted to a series of shallow feeding crops will bring a better yield if it gets a deep cultivation once in a while.

Deep Plowing in Humid Districts

Where the rainfall is overabundant and the soil is likely to become saturated, deep tillage is desirable. It is a well known fact that when the air is excluded by the free soil water the roots die of suffocation. In such cases deep tillage, by affording a loose and open seed bed, allows the free water to seep to a level below the feeding roots and the danger of suffocation is avoided. In many kinds of soil, deep tillage will take the place of underdrainage. These conditions prevail over large portions of the Mississippi valley and the southern states, where the rainfall ranges from forty to sixty inches. Deep tillage is also advisable where the soil is of such a texture that it is likely to wash and gully. Into the open and porous soil the rainfall finds a ready outlet and gradually seeps away instead of running over the surface, carrying the better part of the soil with it. Deep plowing, therefore, is largely a question of locality, climate and soil conditions. What would be regarded as shallow plowing in some sections would be regarded as deep plowing in another.

There is no question that deep tillage is a boon to some soils and the salvation of a wide scope of country, especially

in the south, where for a century or more the fields have been scratched by a one mule plow and a negro. A thorough turning up of these soils, the upper surfaces of which have been packed and leached by the rains of a hundred years, would result in vastly increased yields through the simple fact of soil drainage and the liberation of plant food.

This is not essential in the west where the soil is rich in inorganic matter and the subsoil is not water-logged. Let the farmer understand the nature of his soil, and the scientific principles governing capillarity and the movement of free soil water and he will not go far wrong on the plowing problems. He will be able to know when and where to plow deep and when and where not to plow at all. He will be able to determine from the physical conditions of the soil whether he best use a mouldboard or a disk plow, and whether his furrow should be five or fifteen inches deep. Simply because Mr. Brown plows deep or shallow and gets good results is no reason why yon should do the same, unless you know the physical conditions are identical.

How deep shall I plow? No one can answer that as well as you can if you know your business, and if you know your farm.

Subsoiling

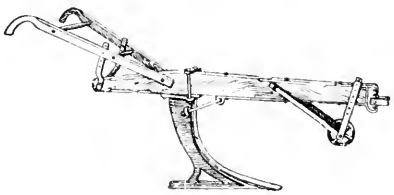
As a general rule, the subsoil does not contain as much humus and available plant food as does the upper, or surface soil. For this reason deep plowing that brings the subsoil to the surface is not the thing for the surface feeding crop. It often takes several years to reduce a heavy subsoil that has been brought to the surface by deep plowing into the proper physical condition to produce good crops. In such cases a subsoil plow that simply stirs the subsoil without bringing it to the surface should be used. Or for moderately deep plowing in such soils a disk plow is preferable to the mouldboard variety. The disk simply loosens the soil and shoves the furrow slice to one side instead of inverting it, thus bringing up the more or less inert subsoil.

Breaking

In discussing the subject of breaking we are assuming that the work is to be done on grass sod. Breaking among the stumps is a back number, for in most sections of the country where there are stumps, dynamite is used to remove them before the breaking is attempted.

The first question naturally arises—how deep shall we plow sod land? Here again local conditions should be taken into consideration, but as a general rule do not cut a furrow more than three inches deep. Let us get at the reasons for this. In breaking prairie the object is to invert the sod and turn it over so that it will rot as quickly as possible. To this end the furrow slice should be turned evenly and the land should be immediately rolled by using a subsurface packer, or a surface roller heavy enough to crush the sod against the firm, moist soil beneath. Then a harrow should be passed over the field immediately to form a surface mulch and fill the crevices. This accomplishes two purposes—first, the air spaces beneath the furrow slice are obliterated and the sod is brought in direct contact with the moist soil beneath, not only establishing the broken capillary connection, but placing it in a position where it will rot speedily and perfectly.

"Why not break four to six inches deep instead of three? Will not deep plowing afford a better root bed for the crops?" you ask. Not as a general rule. If the breaking is to be planted or sowed to a crop immediately, the shallow furrow will afford a better root bed because it can be more thoroughly packed than the deeper plowing. It is a mistaken idea that the roots of the plant must have a loose and open bed in which to grow. What they do want is firm and well hydrated soil. And anyone who is observing will note that the roots of the average plant encounter little or no difficulty in penetrating the soil beneath the furrow slice, providing that portion of the soil contains the proper amount of moisture.



CHAPTER 5

PURPOSES OF SCIENTIFIC TILLAGE

The purposes of scientific tillage of the soil as expressed by King are as follows:

(1) To secure a thorough surface uniformity of the field so that an equally vigorous growth may take place over the entire area.

(2) To develop and maintain a large effective depth of soil, so that there shall be ample living room, an extensive feeding surface and large storage capacity for moisture and available plant food material.

(3) To increase the humus of the soil through a deep and extensive incorporation of organic matter, so that there may be a strong growth of soil micro-organisms and the maintenance of a high content of water-soluble plant food material.

(4) To improve the tilth and maintain the best structural condition of the soil, so that the roots of the crop and the soil organisms may spread readily and widely to place themselves in the closest contact with the largest amount of food material.

(5) To control the amount, to regulate the movement, and to determine the availability of soil moisture, so that there shall never be an excess or a deficiency of this indispensable carrier of food material to and through the plant.

(6) To determine the amount, movement and availability of the water-soluble plant food material present in the soil so that growth may be both rapid, normal and continuous to the end of the season.

(7) To convert the entire root zone of the soil into a commodious, sanitary living and feeding place, perfectly adapted to the needs of the roots of the crop and to the soil organisms—adequately drained, perfectly ventilated and sufficiently warm.

(8) To reduce the waste of plant food materials through the destruction of weeds and the prevention of their growth.

(9) To preserve the soil and prevent waste through surface washing and drifting by winds.

Must Know Soils and Plants

The farmer to till the ground intelligently and effectively must have an intimate knowledge of the structure and physical characteristics of the soil. He must know what the results of certain definite treatments will be. Not only this, but he must be thoroughly acquainted with the habits and demands

of growing crops. He must know how to plan his campaign against the enemy—the army of noxious weeds that is forever invading his territory. He must know, to some extent at least, the relation of plant growth to moisture, temperature and light. So complex are the elements that enter into the problems of plant life and so many are beyond the control of man that it takes, not only a thorough knowledge of the physical laws that govern the relation of the plant to the soil, but it requires a sound judgment, coupled with experience to do the proper thing at the right time. The necessity for knowing things and observing the minutest details cannot be too strongly impressed upon the mind of the reader. Observe all things and hold fast to what is good.

A Confusion of Terms

The terms *seed bed* and *root bed* are used interchangeably by most writers and speakers on agricultural subjects. This is somewhat confusing as the seed and root beds of most plants are entirely distinct propositions, with functions as different as the methods of their preparation. In the preparation of the seed bed, the farmer should keep in mind the germination of the seed and the development of the plantlet. In the preparation of the root bed he should have in view only the growth and maturity of the crop. This mixing of terms that mean entirely different things, like the indiscriminate use of "summer fallow" has been the cause of countless errors with great material loss. In agricultural parlance, "a rose by any other name" does not always smell as sweet. Let us, therefore, fix clearly in our minds the distinction between seed bed and root bed.

The Seed Bed

In the growth of a plant, whether it be a bean stalk or an oak, the first step after the seed is planted is germination—the bursting of the seed cover and the development of the embryonic plant within. And, for the purpose of clearness, we will include in the term germination the putting forth of the plumule and its upward reach to the light as well as the development of the tiny rootlets that establish the plantlet in its relation to the soil. These processes take place in the seed bed—in the first inch or two of surface soil. It will be clear to everyone, that owing to the delicate nature of all newborn plants, this seed bed should be prepared with especial care as to physical texture. Not only that, but care should be taken to see that both the temperature and the moisture content of the seed bed are such that germination will be

quick and the early growth rapid, for upon these first few days of the life of the plant the harvest often depends.

The Root Bed

Below the seed bed lies the realm of the roots—the feeding field of the growing crops. This root bed—this feeding field—is an indefinite and unsurveyed area; it may be confined to the first six inches of soil beneath the seed bed or it may extend to a depth of twenty feet. The extent depends entirely on the "root habit" of the particular plant. As a general statement, however, we would say that the root bed of the average cultivated field crop is found within the first twelve inches of the surface. While the seed bed and the root bed are in a sense distinct, they merge into each other. The lower part of one and the upper part of the other constitute a kind of neutral territory over which the laws governing both extend. It will be seen, therefore, that while the seed bed is under the control of the farmer and gardener and can be prepared by the ordinary tillage implements, it is different with the root bed—only the upper stratum of the root bed can be reached directly by any implement so far invented, although the necessity for thorough preparation is becoming more and more apparent as the laws governing plant growth are better understood.

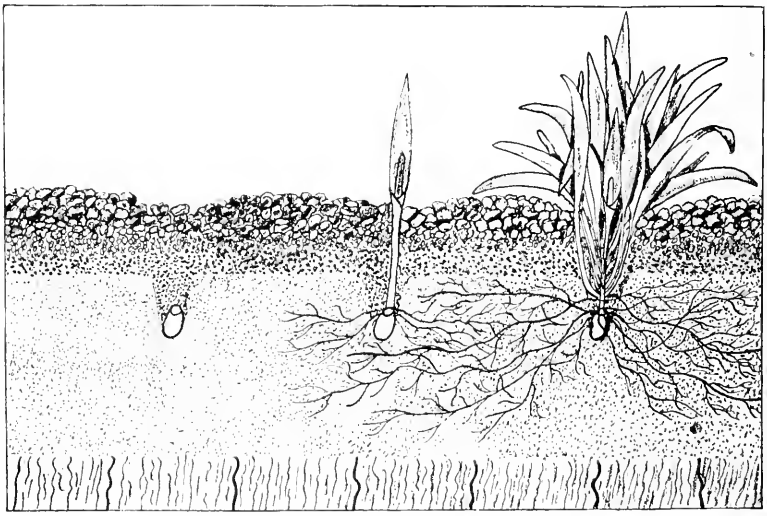


FIG. IX
Showing an Ideal Seed and Root Bed

CHAPTER 6

PACKING AND PACKERS

Surface and Subsurface

The lack of a clear conception of the difference between the seed and root bed is, without doubt, responsible for the confusion that exists in the popular mind in regard to packing the soil. No distinction seems to be made between surface and subsurface packing. The terms clod crusher, surface packer, roller, and subsurface packer are all applied indiscriminately to the same implement. Even manufacturers of a corrugate roller advertise it as a "subsurface" packer. Nor does the babble of verbal confusion stop here. Some speak of "subsoil" packers. And a noted authority in a noted book speaks of a subsurface packer designed to pack the "*subsoil to a depth of from eighteen to twenty-four inches below the surface.*" This looseness of expression is owing to a lack of definite knowledge regarding the principles involved in soil packing. When these principles are once understood, confusion of terms is impossible.

The Distinction

Before going further let us get the distinction between surface and subsurface packing clearly in our minds. Surface packing is a comparatively old practice and applies exclusively to the seed bed. It is accomplished by the roller, the clod crusher, or in some instances, by a "float." The process usually applied after seeding firms and smooths the surface of the ground. Subsurface packing affects the root bed. It is intended to obliterate air spaces left under the turned furrow slice and firm the lower portion of the plowed ground—the object being to pulverize and compact the under surface and reestablish capillary connection with the unplowed portion of the soil. Subsurface packing is one of the new things of the new agriculture and had its origin in the semi-arid west. While there are numerous devices for packing the surface, there is so far but one subsurface packer, composed of a series of skeleton wheels with a wedge-shaped rim that cuts down into the furrow slice with a downward and lateral pressure. The subsurface packer not only pulverizes clods, obliterates air spaces left by the turned furrow, and reestablishes capillary connection with the subsoil, but it also leaves the surface loose and unpacked, thus forming a mulch to protect the packed portion beneath.

Preparation of the Seed Bed

With the distinction between the seed bed and the root bed, and also that between surface and subsurface packing, clearly in our minds, we can proceed with the preparation of the soil for the reception of the seed. A crop that is well started is half grown; and in starting a crop the next thing in importance to pure and virile seed is a clean and well conditioned seed bed. Plowing, the first act of tillage, is supposed to prepare the foundation for both the seed bed and the root bed. If it fails to do this, it has not accomplished its purpose. We will assume that the plowing has been properly done and the under surface firmed by the use of a subsurface packer. The next step in the preparation of the seed bed is to harrow the plowed surface, using either a disk or a spike-tooth harrow, according to the physical condition of the soil, the object being to pulverize all clods, level the surface and establish a soil mulch on the surface to prevent evaporation. This mulch should be from two to two and one-half inches in depth. Bear in mind that we are talking now about the seed bed only.

FIG. X

A Subsurface Packer in Action

Use of Rollers

Seed to germinate quickly must be planted sufficiently deep to come into direct contact with moist soil and the moist soil must be fine and firm, so that the soil particles, surrounded as they are with a film of water, will be closely crowded against each individual grain of seed. This is necessary, not because the seed requires the plant food locked up in the soil grains, but because it needs the moisture. To render this seed bed firm after the fining effect of the harrow, the surface roller or clod crusher is often used with beneficial results. Where there is abundant moisture, or the soil is light in texture, or inclined to be cloddy, the use of the surface roller will, no doubt, hasten germination. This firming of the upper layer of the soil in which the seed is imbedded brings about the conditions necessary to render active the dormant protoplasmic cells of the seed. This is why the gardener, when planting radishes, onions, and other small garden seeds in well prepared beds uses a board to stand on and to firm the loose surface over the rows of seed. And this is also the reason why in the old days of planting corn by hand, the "man with the hoe" was careful to step on each hill as he covered the seed. But in giving the finishing touches to the seed bed the roller, or as it is more often called, the surface packer, should be used with great discretion. A surface packer is a good thing to have on the farm and it is often a good thing to use, but the farmer must know when to use it and when to let it alone.

In the semi-arid west where the soil is likely to "blow" the roller, or the float, should seldom be used, for the reason that both have a tendency to pulverize the surface and leave it at the mercy of the wind. For all purposes of clod crushing and packing, the subsurface packer of the Campbell type that firms the under portion while leaving the surface loose and rough is better. The coarse mulch left by the subsurface packer meets the requirements of the western plains much better than the fine or "dust mulch" left by the roller or the float. The use of soil packers is largely a question of geography and soil physics. The roller and the float may work all right where there is abundant moisture and no high winds, but in the semi-arid west—look out.

Any one can understand that when we attempt to firm the seed bed with a roller the direct effect is to firm the surface only, leaving it smooth and compact. The effect, depending on the weight of the roller, seldom extends more than an inch or two below the surface. This will help germination, but by

firming the surface, it has placed within the upper soil a million little pumps, that in a few days, if nothing be done to prevent, will exhaust the seed bed of its store of moisture. Therefore, when you use the surface packer, follow it immediately with some kind of an implement to loosen the surface again, forming a light mulch to check evaporation. There are individual exceptions to this rule, but it applies generally to all soils and all climates.

The Float

In place of a roller many good farmers use a float made of planks joined together and overlapping like the clapboards of a house for crushing clods and smoothing the surface. This kind of a drag when weighted has much the same effect as the roller, so far as packing the seed bed is concerned. As a clod crusher its action is superior to that of the roller as it grinds the clods instead of pressing them down into the seed bed. The float, too, is a better leveler than the roller, and a level surface for most crops is greatly to be desired, as we shall see later on. A drag made like the celebrated King road drag is used for leveling and packing the seed bed before planting. The King drag may be made of two 2x8 planks ten feet long, placed on edge three feet apart—the ends overlapping about a foot. Cross pieces of 2x6 are mortised in to hold the planks in place; across these, boards are nailed to form a floor on which the driver stands. It is operated at a slight angle. The amount of angle can be governed by the driver shifting his weight.

Preparing the Seed Bed

It is hardly possible to put too much stress on the necessity of thoroughly pulverizing and packing the seed bed. One of the most complete practical illustrations of this was brought out on the demonstration farm at Hill City, Kansas, in the germination and growth of the wheat sown in the fall of 1901. The ground had been prepared with the greatest possible care, having been plowed seven inches deep when the soil was in a moist condition, kept so by disking and harrowing the surface. The plow was followed closely by a subsurface packer and that by an Acme harrow. By doing all the work at the proper time we had secured a very favorable physical condition of the upper soil. At the time of seeding, October 8, 9 and 10, there was a fine, loose mulch on the surface, two and a half inches deep. The soil immediately beneath the mulch was firm and moist. The wheat was put in with a shoe drill,

about one-half inch into the firm moist soil under the mulch. Less than one-half bushel of seed was used to the acre. As a result germination and growth were both rapid. The fourth day, as regularly as the days came, after seeding, the little green spears could be seen the entire length of the rows. On the seventh day these leaves measured from three to four inches. This is not all. On the sixteenth day of November this wheat was taller and thicker than an adjacent field sown the sixteenth day of September with one and one-quarter bushel of seed.

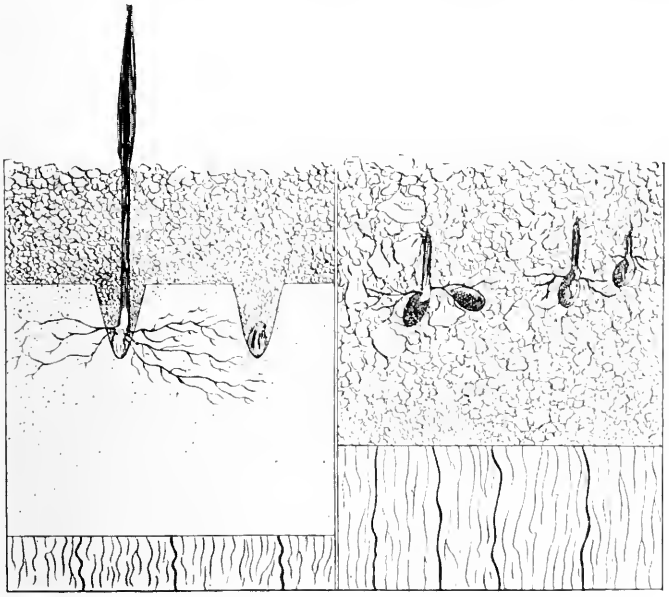


FIG. XI

Showing Proper and Improper Preparation of Seed and Root Beds

Figure 11 represents two conditions of soil. On the right we have the more common condition, prepared without care, the grain of wheat deposited in a coarse, loose soil. In such a seed bed wheat will remain the entire fall without germinating, or it may germinate after a light shower only to wither and die later for lack of a permanent water supply. On the left we have an ideal condition—a condition that can be easily secured with care and without much additional expense.

By the use of the subsurface packer when the soil is in the proper shape, we get the fine, even, firm soil as shown to a depth of seven inches. Then with the harrow, the Acme, or the mulcher we get a soil mulch (not a dust mulch) about two inches deep. With a shoe or double disk drill a V-shaped opening is obtained and the grain dropped about one inch into the firm soil. As it reaches the bottom it is surrounded on all sides but the top with a fine, firm, moist soil. It is all ready to germinate, take root, and come up.

Preparation of the Root Bed

The seed bed should be fine, firm and warm, that the seed may be able to secure moisture. It must also be brought to a temperature that will unlock the prepared food stored in the seed for the use of the plantlet. The root bed should be fine and firm and moist, and warm, that a soil solution may be prepared and impregnated with inorganic plant food, and that the roots may reach out and gather it in without difficulty. The root bed should be put in such a condition that will not only release the greatest amount of inorganic plant food, but which will enable the roots to gather in the necessary food for the plants with the least effort. But while it is a comparatively easy matter to get at the seed bed and put it in condition, it is not so easy to reach the entire root bed with ordinary cultural implements. By what means can the farmer reach and control the conditions of the root bed or the ordinary field crops? This brings us to the subject of subsurface packing.

Subsurface Packing

The best plowing leaves the underside of the furrow slice resting lightly on the compact under soil beneath. When the dry surface, containing always a certain amount of trash, is turned under there will always remain air cavities, the size depending on the physical condition of the soil and the kind of plow used. The connection between the plowed and the unplowed portions of the soil has been broken. It does not matter how deep you plow, the result is the same. The soil of a newly plowed field, if in the proper condition when plowed, is always too loose for either an ideal seed or root bed. Capillary connection with the under soil has been broken, and no matter how compact you get the upper stratum—the seed bed—if a drouth should occur the plant will soon exhaust the moisture in this upper layer, and not being able to get any up from below, it will die of thirst with an abundance of

capillary water just beyond its reach. What is to be done? There is but one thing to do, and that is to pack the subsurface—pack the entire furrow slice so that the air cavities will be filled and connection with the subsoil reestablished. But a surface roller, heavy enough to do that, will pack the top soil to such a degree that it will lose its water content very rapidly through surface evaporation. This result, as we have seen, may be prevented by the immediate use of the harrow. These surface rollers and clod crushers are of no value whatever when it comes to packing the subsurface.

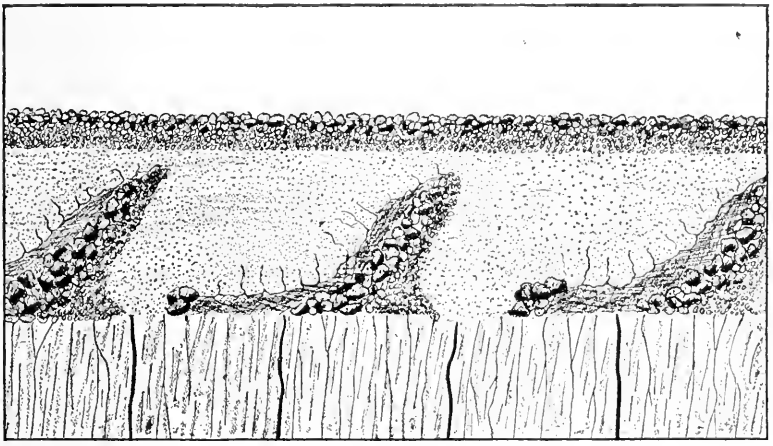


FIG. XII

The Subsurface of a Plowed Field as it Appeared After a Thorough Surface Harrowing

The Subsurface Packer

The Campbell subsurface packer, and those built after the Campbell model, pack the under surface of the furrow slice by means of wheels with a wedge-shaped rim that cuts into the soil from three to four inches, depending on the amount of weight carried by the packer and the condition of the soil. The construction of the packer wheels allows the dirt to fall in above the rims, thus leaving a coarse mulch on the surface. The principles on which the Campbell packer acts are simple and the action effective. It reverses the action of the surface packers by packing the subsurface (not the subsoil), leaving

the surface loose and unpacked. Various implements have been tried to bring about these results, but none so far have turned the trick. A disk harrow, with the disks set straight, is used by some in the place of a subsurface packer; but the very principles on which the disk is constructed make it a loosener of the soil rather than a soil packer. The use of the disk in putting the plowed field in good tilth, without doubt, will help nature do her own packing, but it will never do the work of a subsurface packer any more than a spike-tooth harrow will do the work of a disk.

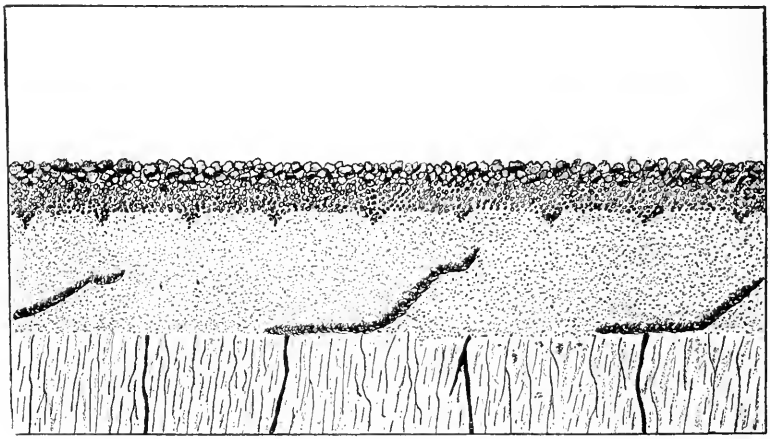


FIG. XIII
The Subsurface of a Plowed Field After Subpacking and a Thorough Harrowing

When to Use the Subsurface Packer

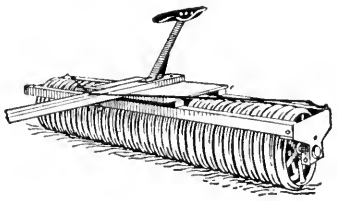
The use of the subsurface packer depends on the soil itself and also on the condition in which it happens to be. Don't use a subsurface packer on every field, nor on all soils at all times. Great discretion should be used. Some heavy soils that pack readily under the action of the weather might be injured by the use of a subsurface packer. Don't pack the soil unless it needs it. If planting is to follow plowing, a subsurface packer should be used. It should follow the plow immediately and in its turn should be followed by a harrow to put on the proper surface mulch.

Advantages of Subsurface Packer

The use of the subsurface packer not only reestablishes capillary connection with the under soil, but by firming the plowed portion it increases the water-holding capacity of the soil near the surface and thus affords the roots a firm and rich feeding ground. The time of plowing has something to do with the problem of subpacking. Fall plowing should be subpacked, but the necessity is not so great as it is in the case of spring plowing, for the reason that nature, through the agency of the frosts of winter and the rains of late fall and early spring, if there are any, will do to some extent the work of the subsurface packer. But if there should be no fall nor spring rains, as is often the case in the semi-arid west, there will be little packing done by nature. It is better, therefore, to use the subsurface packer on fall plowing than to take any chances on nature doing the work. On spring plowing, however, when a crop is to be planted immediately, the subsurface packer should never be omitted. It should follow the plow, and the deeper the plowing the greater the necessity for packing.

Prevents Soil Drifting

The fact that subsurface packing will prevent to a large extent soil drifting is pretty well established. The scientific principles involved are not clearly understood, but it is believed that a well packed soil, possessing as it does a high degree of capillarity up to within a few inches of the surface, retains its vitality longer and imparts that virile condition even to the surface mulch. Whatever be the reason, the universal experience from North Dakota to Texas has been that, while fields handled by the ordinary methods and unpacked were blown out of their fences, the subpacked field remained uninjured.



CHAPTER 7

CULTIVATION

Surface Cultivation

With the root bed made fine and firm and the seed bed properly prepared, the seed germinated and the plants above ground, the next act on the program is cultivation. The surface of the ground must be so handled that the moisture will not escape by evaporation nor the weeds pump it out.

How deep shall we cultivate? This question is the twin of how deep shall we plow. Neither can be answered unless the soil and climatic conditions, the kind of crop or crops that have previously occupied the soil, as well as the kind of crops to be grown are all known. A deep-feeding crop will be benefited while a shallow-feeding crop will be ruined by deep cultivation. Leaving out of consideration the root habits of the crop to be grown, level surface cultivation has certain advantages that ought to be understood by every farmer. It was once thought necessary to hill potatoes, and in many localities, especially in the south and east, deep cultivation is recommended for both corn and cotton. This advice may be good if the land is not well drained. As a surface drainage scheme this may have some virtue, but from any other point of view it is a bad practice. Let us get at the facts.

The potato is a deep feeder. If the seed and root bed be properly prepared the roots will spread out in every direction where there is moisture. If the surface of the field be kept level with a proper mulch on top, the soil moisture will be brought up and held near the surface within easy reach of the roots. Now, if the interspaces be cultivated deeply, so as to ridge or hill the potato plants, not only will many lateral roots be cut or exposed, but a larger surface will be exposed to the drying action of the sun and wind, while the actual feeding ground of the roots—the root bed—will be narrowed and limited to the few square feet about the hill. The same principles apply to the cultivation of corn and cotton. Shallow culture not only conserves the greatest amount of moisture, but it widens the root bed, increases the available feeding ground and leaves the field in better shape for the next year's tillage. And this brings us to another question—shall we employ ridge or level culture?

Level Culture

A certain degree of heat is absolutely necessary to the germination of seed and the growth of plants. It is necessary because the chemical action that takes place in the awakening of the germ of the seed and the assimilation by the plantlet of the stored food demands a certain degree of heat. In addition to this, the physical process known as osmosis, by which the roots of the plants gather in the solution is hastened by a high soil temperature. We know, also, in a vague way, that the microscopic organisms that inhabit the soil—the soil bacteria, that contribute so much to the health and growth of plants, thrive best in optimum soil temperatures. We know positively that the higher the temperature of the soil moisture, the greater will be the liberation of inorganic plant food and consequently the richer will be the soil solution. With these facts in mind it is easy to see the advantage of any system of cultivation that tends to quickly and permanently warm the soil, and this where the soil is well drained is accomplished best by level cultivation. As a general rule, and for a large majority of crops raised by inter-tillage, level culture is advisable. It hastens germination of the seed by increasing the soil temperature; it produces an even distribution of soil moisture and plant food. As a result the stand is regular and even and the grade of the ripened grain uniform.

Ridging and Listing

In some localities, especially in the south, where spring rains are likely to be excessive, the natives practice ridging for corn and cotton. Two furrows are backset and the seed planted on the ridge, or four furrows are backset and the seed planted along the edges of the dead furrow. The object of this method is to save the young plants from drowning by supplying a means of surface drainage to carry off the surplus water. This is but a make-shift and should have no place in the permanent agricultural practice of a community. Deep plowing and underdrainage will accomplish the same results, leaving the surface level and the available inorganic plant food evenly distributed throughout the seed and root beds.

Where the rainfall is supposed to be insufficient, or unreliable, the practice of listing is extensively employed, especially for corn. Listing is just the reverse of ridging. A double furrow is thrown up and the seed deposited in the ditch thus formed, the idea being that the deeper the plant is rooted, the better it will be able to stand a drouth—or, in

other words, the deeper it is planted the better able it will be to secure moisture from the soil. This, as we have seen, is not necessarily true. If the firm soil of the root bed is deep, the seed should be planted within easy reach of it. The practice of listing corn presents the advantage of a rough surface which is to a certain extent a protection against soil drifting in sections where high winds prevail. It has an advantage also in the fact that the inter-culture that follows never interferes with the main roots of the plants. These observations are sufficient for our present purpose.

As to Time of Cultivation

The proper time for cultivating a field is one that cannot be fixed without much thought, observation, and judgment by the farmer, especially if he would get the best results. Always cultivate immediately, or as soon after a rain as conditions will permit you on the field, and the soil is sufficiently dried so that it will not adhere to the cultivator teeth, or tools used. We do not mean by this that the soil should be absolutely dry on the surface. It is an error to wait for that time, for the moment the surface is apparently dry the crust begins to form. It is desirable to catch the ground just before this time when all the soil is simply moist and then there is a free and ready separation of all particles. In this condition the cultivator runs the easiest, the mulch made the finest and lies up light and loose. If the soil is a little too wet it settles, and not infrequently forms absolute and perfect connection with the firm soil below, steadily carrying moisture to the surface. If too dry the cultivator produces an imperfect mulch that gives us but little protection.

Another very important fact is that every moment's delay after the soil reaches the proper condition causes you to lose water very fast. It is at the rate of a quart or over per square foot per day, providing it is clear sunny weather, and even more in case of hot winds. The more intense the heat the more frequently it is necessary to cultivate. A very good rule is to watch the condition of the firm soil just beneath the loose mulch or cultivated portion, and whenever the surface of this firm soil begins to show dryness it is high time to commence cultivating again.

CHAPTER 8

THE SOIL MULCH

Evaporation

Evaporation of moisture takes place from the surface of a body of water, or from the exposed surface of most materials. It is increased by a continuous change of air and a high temperature. Constant winds, and a hot, dry atmosphere are favorable to rapid evaporation from damp surfaces exposed to the air and sun. If you want to prevent evaporation from a tub of water you would cover it up. If you want to prevent evaporation from the surface of a field, cover it up. To protect the roots of the orchard trees and the small fruits in the garden from the frosts in the winter, and to keep the ground about them cool in the spring and moist in the summer our grandfathers covered the ground with a layer of straw, forming a straw mulch. Nature does the same thing annually when left to herself—she covers the surface of the ground with a mulch of grass or leaves. This not only arrests the rainfall, but prevents evaporation to a degree depending on the thickness of the mulch. Throw a blanket on a lawn and, although no rain falls and the blanket appears perfectly dry, in a few days the soil under the blanket will be damp clear to the surface. Now, to prevent evaporation from a cultivated field, cover it up with a mulch, not of leaves, or grass, or straw, but of particles of earth that will act as the lid on the tub of water, or as the blanket on the lawn. This mulch can be formed with the harrow, either the disk or the spike-tooth, and can be maintained by the ordinary cultural implements adapted to the crop being grown.

Avoid a Dust Mulch

Loose talkers and equally loose writers on agricultural subjects have advocated the maintenance of a "dust mulch," and apply that name to all soil mulches. This is much to be regretted for it leads to all kinds of confusion. The farmer is advised to maintain a "dust mulch" when a soil mulch made up of small dirt clods from the size of a pea to that of a large marble is desired. A dust mulch renders the surface soil lifeless and easily crusted and even puddled by a dashing rain. It also forms an almost impervious barrier to percolation—it repulses the moisture from both below and above. When the harrow is used immediately after the plow, or following a rain, the surface will be left in an ideal condition to prevent

the loss of the moisture already in the ground and to receive future rainfalls. It is often necessary to work ground until the surface is reduced to something like a dust, but this condition should be avoided as far as possible.

When to Establish a Mulch

The most important factor in the problem of crop production is the conservation of soil moisture, and we use this word conservation in its fullest sense, meaning not only gathering and holding it, but so holding it as to render available to the plant, food within the soil solution. The mulch being the lid to prevent the escape of this moisture, the when and the how of its placing on are of vital importance. While a crop is growing, and while it is standing on the field it prevents, to a large extent, evaporation from the surface of the soil. But when it is removed, the wind and the sun begin to pump out the moisture and carry it away. This is especially true of small grains and grasses that have covered the land like a blanket, shielding the surface from the direct rays of the sun and the sweep of the wind. The mulch, therefore, should be placed upon the field as soon as the grain is removed.

Disk Should Follow Harvester

No time should be lost in putting on the lid—not even a day. The disk harrow which is the best possible implement for this purpose should follow the harvester, cutting the stubble and slicing the surface crust, thus forming a mulch that will not only prevent the evaporation of the subsoil moisture, but facilitate the absorption of any subsequent fall rains. The benefit of disking the stubble, however, does not stop here; it brings the soil moisture from below up to the under surface of the mulch and holds it there. No matter how dry the surface crust may be at harvest time, if there is any moisture in the soil, and there usually is, if the field be thoroughly disked at once, you will note that in a week or ten days the soil immediately under the mulch is moist and in prime condition to plow.

Disk Before Plowing

The above is one reason why all fields, especially in the fall, should be disked before plowing. There are other reasons which are equally as cogent. For instance, the seed and root beds are left in much better shape by the plow if the surface has been thoroughly fined by the action of the disk. This will become evident if you give it a moment's thought. Whenever a field with a rough or uneven surface is plowed—a field

that has been in corn or potatoes and which did not receive level culture the previous year, and which also is covered with corn stalks or other rubbish—the furrow slice never completely fills the vacant furrow with a compact, well pulverized soil, but leaves the surface uneven and cloddy. But this is not the worst of it—the surface can be easily taken care of—the trouble is with the subsurface. This is left full of air spaces caused by the rubbish and clods from the uneven surface holding up the furrow slice. This condition can be largely remedied and a much more compact seed and root bed left by the plow if the surface crust, the clods and the rubbish, has been subject to the action of the disk. These results of plowing disked and undisked ground are shown in figure 20 page 89.

Harrowing Small Grain

Small grain should be harrowed to destroy weeds and maintain a surface mulch. When a heavy rain forms a crust on the surface of a wheat field when the wheat is not sufficiently high to shade the ground, more moisture will be lost by evaporation than fell as rain unless the crust be destroyed by some light cultural implement. To kill weeds in a young wheat field, or break up any crust that may form, the spike-tooth harrow is usually used. The harrow should be used with the teeth set back. If the stand is too thick, the harrow should be drawn at right angles to the drill rows, otherwise in the same direction. The objects of harrowing small grains are to conserve the moisture, kill the weeds that may be starting, and to thin the stand when too thick; but the principle object is to bottle up the moisture and hold it for the plant. In the spring, when the winds are high and the stand of grain is small, evaporation from an unmulched surface is very great. It is then that the plant needs the moisture near the surface in the region of its roots. If a light mulch can be maintained until the plant gets larger so that it will shade the ground, the danger from excessive evaporation is much less.

When to Harrow

Do not harrow grain simply to be harrowing. If there is no moisture to conserve, no crust to break, nor weeds to destroy, there is no need to harrow. There is no virtue in simply doing the work if there is no demand for it. The man who resolved to harrow his wheat every week knew neither the why nor the when of his work and would be likely to do his field more harm than good. Care must be taken to catch

the soil when it is moist, if possible. The best time is when the grain is beginning to stool, or when it is about four inches high. If, however, the field should pass through the spring without rain enough to settle the mulch, it is not necessary to harrow—nothing is to be gained; but if a heavy rain comes and settles the mulch, you must harrow again. The mulch should be kept in good shape until the foliage covers the ground. The loose surface will facilitate the free circulation of the air, so much to be desired.

Harrowing Corn

The harrow can be used with beneficial effect on the corn field after the plants are well up, especially where level culture has been employed. The principles involved and the objects to be obtained are the same as in harrowing smaller grain—the formation of a mulch to prevent evaporation and the destruction of young weeds. Harrowing a field of corn or any other inter-culture crop after a rain is the most effectual and economical method of saving the moisture and at the same time preventing weed growth. For this use a weeder is preferable. The spike-tooth harrow can be used, but the teeth must not be set too slanting or they will tear out the corn. This method of culture can be employed until the corn is a foot high, providing the work is done only in the afternoon, when the corn plant will receive a great deal of punishment without injury.

The Subsurface Crust

When the hot sun of June and July beats down on the cultivated fields, the temperature of the soil mulch will often rise above the 100 limit. This is good for the crops if they have a plentiful supply of soil moisture within reach of their roots and the soil circulation is all right. But this excessive heat brings up the soil moisture through the capillary tubes with the energy of a force pump. And coming from below, this moisture contains various salts in solution. As it rises a great part of it is absorbed by the roots which select the mineral ingredients needed; the remaining solution heavily charged with inorganic matter rises until it reaches the under side of the mulch where the excessive heat turns it into vapor which escapes through the mulch into the outer air, leaving the salts behind. This, if allowed to continue, will soon form a crust between the mulch and the moist soil beneath. When once formed, this crust shuts out the air—actually seals up the soil, and although there is plenty of moisture beneath the crust

the crop will wilt and die, not because of a lack of moisture, but because the respiration is shut off. The plants will suffocate.

The Remedy

The remedy for this condition is not deeper cultivation, for that in most cases means the cutting off of the main feeding roots of the plants. The remedy might be worse than the disease. The thing to do is to prevent the crust from forming by timely cultivation. This crust is likely to form under the mulch in the corn fields during excessively hot seasons. A careful watch should be kept on the condition of the soil just beneath the mulch. When this begins to show signs of hard-

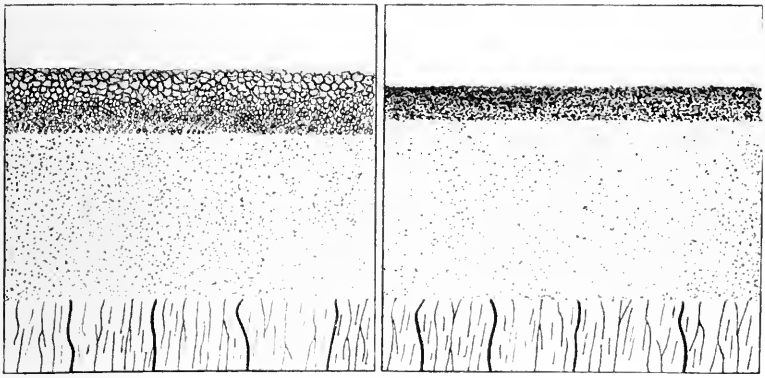


FIG. XIV

Showing the Effect of a Rain in Settling a Soil Mulch

ness, get into the field at once and stir your mulch, break up the capillary channels that are letting the steam out and evaporation will cease and the crust will not form. Caring for a field of corn so that a subsurface crust will not form during, long, hot, dry spells is a sure test of the knowledge and ability of the farmers of the middle west. A word of caution and another of advice might not be out of place here. If the weather is hot and dry, and so continues for a number of days, no matter how complete your mulch appears, nor how thrifty your corn looks, go over your field and here and there scrape away the mulch and feel of the soil beneath. If you find signs of a forming crust, get busy. Don't go any

deeper with your implement, but stir the mulch and keep it stirred until the danger is over. You may thus be able to save a crop.

Keeping the Mulch in Condition

There are many important reasons why great care should be taken to keep the mulch in perfect condition and prevent the loss as far as possible of any moisture by evaporation from the surface of the soil. The following paragraph taken from King's book on The Soil conveys some important information along this line. We quote this because it bears the figures of his own practical observation at various depths in the soil, showing the effect not only of the surface soil getting too dry but of light showers. He says:

"When the surface soil has its water content reduced so the upper six to twelve inches are beginning to get dry the rate of capillary rise of water through it is decreased and it begins to assume the properties of a mulch. But when this condition has been reached, if a rain increases the thickness of the water film on the soil grains without causing percolation, the capillary flow may be so certain that the surface foot draws upon the deeper soil moisture at a more rapid rate than before, causing a trans-location of the lower soil moisture, the deeper soil becoming measurably drier soon after such a rain than it was before, while the surface foot is found to contain more water than has fallen upon it."

The Primitive Hand Harrow

CHAPTER 9

SUMMER TILLAGE

The Agricultural Trinity

To plow, to sow, and to reap, are the three acts of the great agricultural drama as it has been played for fifty thousand years. It has never varied from the stereotyped formula. Generations have come upon the stage, have spoken their little lines, performed their little stunts, and made their exits.

To plow, to sow, and to reap, has been for centuries the agricultural counterpart of Faith, Hope and Charity. With Faith our fathers plowed, with high Hope they sowed, and trusted to the Charity of nature to reap. They plowed the best they could, they sowed their seed, hoping for the best, and then trusted to the sun and the fickle rain to bring the harvest.

In all the wide field of literature we find little or nothing of tillage—of the effort to assist nature in her wonderful work. Even in the parable of the sower, representing a condition of scarce two thousand years ago, there is no reference to the preparation of the seed bed nor after cultivation: "Some seed fell on stony ground where it had no depth of earth, and immediately it sprang up because it had no depth of earth; but when the sun was up it was scorched, and because it had no root it withered away; and some fell among thorns, and the thorns grew up and choked it, and it yielded no fruit; and others fell on good ground and did yield fruit and sprang up and increased and brought forth—some thirty, some sixty, and some one hundred-fold."

Tillage, the scientific treatment of the soil, is of very recent origin. It came with the passing of the old regime—the regime of the "man with the hoe." To the ancient agricultural Trinity, to plow, to sow, and to reap, has been added "to till"—these three, and a fourth, and the greatest of these is—"to till."

Old Art But New Science

From the time of Adam and the Garden of Eden, the growing of crops has been the chief industry of the human race. And during all centuries, soil culture in some form has been considered necessary to secure reliable returns in grain and fruit. Through the slow process of experience and the invention from time to time of improved implements,

better methods have gradually come into use. It is but recently, however, that the education of the farmer in the art and science of soil culture has been seriously considered. It can be truly said, therefore, that soil culture is one of the oldest arts and one of the most recent of sciences. One of the latest developments in the science of soil culture, and one that opens up great possibilities to the farmers in the socalled semi-arid regions of the world where the precipitation averages less than twenty-five inches per annum, is the process known as "summer tillage."

Encounters Opposition

Although the principles of summer tillage have been demonstrated to be sound, and although the practice, where the details of the theory have been carefully carried out, has been successful for a number of years, yet it is very imperfectly understood by the average farmer of today. The theory and practice of summer tillage, like most new things, met with prompt disapproval and determined opposition. The new cult was met with predictions of disappointment and crop failure, not to mention dire prophesies of an early depletion of soil fertility. "The theory is all wrong," said the agricultural authorities,—"you can get better results from crop rotation." But in spite of the opposition and the adverse criticism, one important fact remained clear—good crops obtained by summer tillage beside total failures under the old system. Why this difference under identical conditions of soil, climate and rainfall? What is the logical, the scientific conclusion? No fertilizers have been used—it must be the result of tillage.

Precise Knowledge Essential

In this book we give you the results of twenty-five years of practical work in the fields; it is the vital link in the entire chain of scientific soil culture in the semi-arid regions of the world. We urge you, therefore, to study the following pages with extreme care, that you may not only fully comprehend the principles involved, but note and remember every detail of the process, for your success with summer tillage depends upon the preciseness with which you carry out the minute details of your work.

The Fallow Field

The belief that cultivated land needed an occasional rest was doubtless responsible for the practice of "summer fallow"—

a practice that is nearly as ancient as agriculture itself, and which is still followed by the non-progressive farmers in every community.

The fallow field was a familiar division of the old time farm and the manner of treatment given this fallow field was a pretty good index of the disposition and intelligence of the farmer. But do not get the idea that this practice was confined to "old fogies" or to the less intelligent farmers in the community. On the contrary, it was taught by the agricultural experts and in many agricultural bulletins you may still find "summer fallow" in the regular schedule of crop rotation.

The Rest Theory

The practice of summer fallow varies, not only with the disposition and intelligence of the individual farmer, but with the custom of the community. Here is a farmer who is convinced that his land is tired and needs a period of rest, so he allows his field a complete vacation—abandons it for a year or two to a riot of weeds and native grass; here is another, a shade more thrifty who lets a field lie fallow but uses it as a pasture for his sheep and young cattle. The grass and weeds are therefore kept closely cropped; here is another who has a field infected with sorrel, or some other persistent weed, being thrifty and something of a thinker as well, he not only pastures his fallow field, but plows it in midsummer to destroy the obnoxious weeds by exposing their roots to the summer sun before they have time to seed. His neighbor did the same, but his field had not been pastured, consequently a rank growth of weeds was turned under before they had time to seed. The result was a slightly increased yield in the next year's crop in both cases. The conclusions, however, regarding the cause of this increased yield were totally different. The first one concluded that the result was due to the rest given the land and the further fact that grass and weeds were kept down. The other was sure that the result was owing to the turning under of the crop of weeds—that this acted as just that much manure and the increased yield was due to this natural fertilizer.

A Modern Definition

Thus it will be seen that the rest theory became coupled with the theory of weed fertilization in the practice of summer fallow. No one seemed to realize that weeds, being voracious feeders, take more from the soil while growing, than they can possibly give back. No one seemed to remember that the

principle of compensation—that you can't get something for nothing—applies to soil culture as well as to trade.

Aside from the eradication of weeds and a slight improvement in the tilth of the land, owing to a very small addition of humus from the weed crop, the old process of summer fallow is of little or no value in farm management. In the light of modern scientific methods it is difficult to realize how the old-time farmer came to believe that a crop of grain was harder on his soil than a crop of weeds. But he did believe it, and many still believe it, in a sort of unthinking way. Even as late as 1906, in a bulletin on crop rotation, issued by the agricultural college of South Dakota, Professor Chilcott, commenting on the practice of summer fallow in the experimental work, said: "The summer fallow plots are plowed in July before the weeds have ripened their seeds, and are plowed again with the other plots in the fall. They are given no other cultivation during the season."

A Complete Revolution

The above may be taken as an authoritative statement of the methods of summer fallow up to that date. A complete revolution in the methods of handling the fallow field has taken place within the last ten years. Clean cultivation, intelligently applied, has superseded the old method. This practice has become known as summer tillage and is as different from summer fallow in object, principle, and practice, as success is from failure.

Claims of Summer Fallow

Before going further into the subject let us clearly understand what was claimed for summer fallow and what advantages if any, it had over constant cropping.

The theory that land under cultivation, like a tired work animal, needed a period of rest, failed under the test of investigation. It was found that an exhausted field under certain conditions might require extra food—manure or an application of some mineral substance in which the soil seemed deficient, in order to secure normal yields, but to allow it to rest for the mere sake of resting was on a par with the practice of planting potatoes in the moon. We, therefore, will put the "rest" theory on the shelf with the other dust-covered curios—it is useful only as an index of agricultural progress.

Destruction of Weeds

Summer fallow, however, had some value depending on the soil conditions. If a field had become foul with noxious

weeds, a plowing in midsummer before the growth had time to mature would make the cultivation of the next year's crop a much easier task. The yield was likely to be somewhat greater because of the destruction in mid-season of all plant growth, resulting in a slight accumulation of plant food in the soil. If the summer plowing was timely and had been well done, it would, perhaps, result in a larger and better distributed supply of moisture in the subsoil.

Other Fancied Advantages

Crop-sick land doubtless was benefited to some extent by the summer fallow. The change in plant growth and the exposure to the elements would naturally assist in clearing the soil of toxic poisons. The theory that the old practice of turning under a crop of weeds benefits the land by adding plant food is, to say the least, questionable. That it adds a slight amount of humus to the soil may be true, but with most soils the game is not worth the candle.

We, therefore, will pass to the discussion of summer tillage, a process totally different from summer fallow, but which, owing to a lack of definite knowledge of the principles involved, is often confused with summer fallow, many careless writers using the terms interchangeably. The student of scientific tillage is, therefore, cautioned to scan carefully whatever he reads about summer fallow and summer tillage, keeping in mind always the radical difference.

A New Departure

Summer tillage is a new departure in the process of soil culture. It consists of a combination of certain kinds of work, under certain soil and climatic conditions, and at certain opportune seasons of the year. The one object in view is an increased crop yield, to be brought about through conservation, regulation and control of the water content of the soil, and the maintenance of a soil condition favorable to the liberation of natural plant food. This condition is brought about by the regulation of air and moisture in the soil, and to some extent the temperature, by thorough and timely cultivation.

While the essential scientific principles underlying the theories of summer tillage are old, their application is comparatively new. Coming, as it did, in response to the call of the semi-arid west, the prevailing idea is that summer tillage applies only to the regions of insufficient and unreliable rainfall. Although its application to the conditions of the more

humid sections has not been fully proved, yet from results of the application of the principles in the semi-arid sections it seems reasonable to predict that the practice will prove of great value under any and all conditions of soil and climate, especially where fertility has become depleted.

Objects of Summer Tillage

That the reader may observe and understand the wide difference between summer fallow and summer tillage we will state briefly the objects sought to be attained by the latter. First, an increased yield, far above what is considered a good crop, not only every second year, as is popularly supposed, but when the system has once been applied and the moisture of the soil and subsoil got under control, a bumper crop may be expected each year as long as the water content can be kept at the optimum, providing always, that the work in the preparation and tillage of the soil is properly done. Second, the insurance of the crop against failure through drouth. Summer tillage, when properly carried out, under reasonably favorable conditions is an absolute guaranty against crop failure in drouthy seasons. This is brought about by the storage in the soil of a large amount of the annual precipitation. which is so held that it is made available, not only to the plant when needed, but becomes so thoroughly charged with plant food in solution, that it is found possible to carry a crop through a long period of drouth with much less water than would otherwise be required.

Essential Conditions

The foregoing are the primal objects of summer tillage, but these objects cannot be attained by haphazard methods. There are certain conditions that must be carefully observed and their meaning understood, if good results are to be secured. The storing and conservation of water is of vital importance, yet the kind of cultivation and the specific conditions of the soil at the time of cultivation are also important and must be watched. The work must be carefully and timely done if the phenomenally large yields are to be obtained.

The persistent destruction of weeds is a condition that must be insisted upon, for we have learned by experience that even small weeds are great drinkers and pump the water out of the soil wonderfully fast. Therefore, a summer tilled field must be kept absolutely clear of weeds at all times.

Increases Soil Fertility

The first and most important result from summer tillage is the release of the natural fertility of the soil—the inorganic elements—and to render it available as plant food. This is brought about by various chemical agencies that act with the greatest efficiency when the soil carries a certain percent of both moisture and air. Just what the percent is that gives the best results is not accurately known—it doubtless varies with the texture of the soil—but experience indicates that the water content should be near the highest limit of capillarity and that there should be sufficient air to supply the oxygen needed by the roots in the process of cell formation. To secure this ideal combination of air and water, the soil composing the seed and root beds should be made fine and firm with a loose mulch covering the surface to prevent loss of moisture by evaporation, for the moment the moisture content is reduced, either by direct evaporation from the surface, or by transpiration through weeds the delicate balance is disturbed and the chemical action in the soil is checked in the same proportion.

A second result of summer tillage, in fact a direct corollary of the first, is a marked decrease in the amount of water necessary to produce a pound of dry matter. The amount is less owing to a decrease in the demand of the growing crop, due to an increase in available fertility.

Not Necessary Every Alternate Year

It must be thoroughly understood that in order to obtain the largest annual profits from your fields, summer tilling is by no means advisable each and every alternate year, except where the average annual rainfall is less than fifteen inches, and even then with certain soils and a well distributed rainfall it is possible to store the available moisture, so that two and possibly three crops may be grown in succession. This will depend, however, on the care with which you handle your soil and the persistency with which you conserve the moisture. Your guide in this matter should be always the condition of your soil, and the amount of soil water you have in reserve at the close of each crop season. With a close consideration of these two points you can easily determine whether there is a sufficient amount of moisture in reserve and whether the land is in condition to grow another good crop, or whether it should be summer tilled again.

The First Steps

It is said that the education of a child should begin with his grandfather; so it is with a field to be summer tilled. The

work should begin the year before. As a general proposition summer tillage cannot be carried out in its entirety and the best results obtained until one or two crops have been grown. The first step—a thorough double disking of the ground—should be done as soon after the crop is removed as possible. The advantages of double disking the land immediately after the crop is removed, especially if it be a crop of small grain, are four-fold:

First, by forming a surface mulch it conserves the moisture already in the soil.

Second, by presenting a loose surface the autumn rains are more readily absorbed and retained by the subsoil.

Third, the stirring of the surface soil hastens the germination of all weed seeds and volunteer grain, the young growth of which should be destroyed by subsequent cultivation.

Fourth, the condition of the soil as to water content, thus produced, together with the high soil temperature of late summer, favors bacterial activity, and brings about a chemical action that results in the liberation of inorganic plant food.

No Time Can Be Lost

No time should be lost in beginning the work. In the case of a field of small grain the disk should follow the binder, for what moisture is left in the ground will evaporate very quickly after the shading effect of the standing crop is removed and the hot rays of the sun are allowed to beat upon the compact surface and dead stubble. It is very important to conserve this moisture. The loosening of the surface by the disk checks the upward movement of the soil moisture, causing it to accumulate in the firm soil just beneath the mulch. This regulation of the water content not only increases chemical action in the soil, but also increases the capacity of the soil for absorbing and retaining subsequent rainfall.

The Little Things Count

The importance of this early fall work is governed largely by local climatic conditions and the amount of annual precipitation that may be expected. In sections of the country where the average annual rainfall is less than eighteen inches, it should never be omitted, as the harvest may be followed by a drouthy year, and the moisture that may be conserved by this early work may be just enough when added to the regular precipitation to carry the crop to maturity, when without it—although the amount may be small—the crop would fail.

It is often the little and not the big things that make for success or failure. It must be remembered that plant growth continues just as long as there is available moisture at hand—not that moisture is the only necessary element, but all other elements are worthless without it.

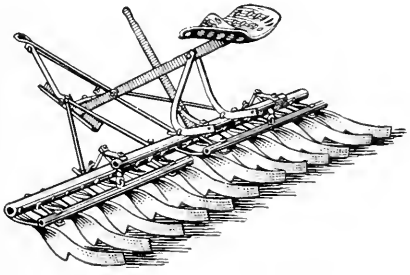
How to Begin

As stated in the preceding paragraph, the first step in summer tillage, after a crop has been removed, is to double disk the land. If the crop on the field to be summer tilled was small grain, the disk breaks up the surface into small lumps and mixes the stubble with the loosened soil, forming a mulch. The efficiency is not destroyed by subsequent rains because the stubble, by keeping the mulch from becoming compact, prevents the heavy rains from completely reestablishing capillary connection with the moist under soil and consequent rapid upward movement of moisture and evaporation.

Destroy Weeds and Volunteer Grain

When heavy autumn rains follow harvest, causing ideal growing conditions, weeds and volunteer grain will spring up wherever the seed has fallen. This growth can usually be destroyed on the land that has been double disked, by the common steel harrow if the work is done quickly, before the grain and weeds become too well rooted.

No time should be lost in getting into the field as soon as the weeds appear above the ground. Here a "stitch in time saves nine," for weeds are not only great drinkers, and when still very young, use an immense amount of water, but every day they are left unmolested they become more firmly rooted and are the harder to eradicate. A growing weed is the most expensive thing that can be kept about a farm.



CHAPTER 10

STORAGE OF MOISTURE

The beginning and the end of summer tillage is the conservation of moisture—the storing of water in the soil as in a reservoir. The old-time irrigator stored the surplus water of running streams in an artificial reservoir and turned it onto his fields when he thought his crops needed it. The modern scientific farmer stores the rainfall in the soil and holds it there ever ready for the growing crop when it is needed. There is another difference; the old-time irrigator loses half of his stored water by evaporation from the surface of his reservoir and in the process of applying it to his field. But in summer tillage very little moisture is lost by evaporation, and, as we shall see, the water, while stored in the soil, is not idle, but is busy dissolving inorganic matter for the use of the plants.

The Soil as a Reservoir

That water, whether it be applied artificially by irrigation or falls in the form of rain and snow, can be stored in the soil and held there for the use of a crop, is a new proposition in agriculture. It is so new that only a very few of the world's experts in soil culture understand the methods by which it is done, or appreciate the far-reaching effect of the discovery. In fact, the general opinion is that it cannot be done. But in the face of this opinion it is being done by thousands of experimenters and practical farmers in the so-called dry farming sections and in the irrigated districts every year. In fact, it has been demonstrated, that the best results in the growing of fruit orchards and cultural crops in the irrigated sections of the arid west are obtained from one irrigation a year. The universal success of summer tillage methods applied to irrigated lands is completely revolutionizing the method of the application of water with the result that the irrigable acreage of the world will be increased four-fold. This is also true of the semi-arid area of the world.

What to Do in the Spring

Now, let us go over the process of summer tillage step by step, seeing that everything is done that should be done, and learning, if possible, the reasons for the various steps. The field designed for summer tillage, that has been disked in the autumn and kept clear of weeds, as we have outlined,

will have absorbed a great part of the autumn and winter rains, and if there has been a fall of snow, that too will soak into the soil at the opening of spring. The first problem, then, is to hold this water in the soil—to prevent its evaporation during the warm and windy days of early spring. How can this be done? Put a lid on as soon as possible. Get onto the field with a disk harrow as soon as the condition of the top soil will permit. Don't wait until it is dry—get on while it is yet wet, and double disk it; break up the surface crust, if one has formed, and put in its place a mulch of small clods—not a dust mulch, for that would be fatal, especially where high winds are likely to prevail during the spring months. You want a coarse mulch—one that will not blow, therefore, disk the ground when it is sufficiently wet to roll up into little balls from the size of a pea to that of a walnut.

Depth of Disking

The depth to which the disk should cut depends upon the condition of the surface. If the surface be already loose, set the disks so they will run light and cut shallow. If there is a crust formed and the surface is getting somewhat dry, set them at a greater angle and cut deeper—deep enough to turn up the moist soil. Be sure to double disk by lapping your implement one-half. The reason for doing this on land to be summer tilled is that it leaves the surface comparatively level. If you use the single disk, there is left, after each round, a back furrow where the outside disks throw up the dirt that is removed from the center, and an open furrow formed by the action of the inside disks. Here, in the absence of a mulch, evaporation will take place rapidly and a crust will quickly form. This defect the double disking corrects, leaving the surface with a uniform mulch, level but slightly ridged and cloddy. This is what is desired. If conditions will permit it, a shallow mulch is best for the reason that the rainfall will more readily soak into it, and then, too, the weather being cool and the evaporation slight, a deep mulch is unnecessary.

After the First Rains

When the disked surface has become packed by the first rains, it should be loosened at once with an Acme, or a spike-tooth harrow. This work should be done without delay, while the ground is yet moist, because a mulch made from wet soil will not drift, and for the further reason, that in this condition a much lighter mulch will do—and the lighter the mulch at this time of the year, the better, because, as above

stated, the rainfall will be absorbed more readily than by a deep and fine dust mulch. The reason for this is, that moist soil has a greater attraction for water than has dry soil. So, the nearer to the surface we can keep the moist earth and still protect it from evaporation, the more readily will it take in the subsequent rainfall. If the soil can be kept moist near the surface, as soon as the mulch becomes wet, the water will percolate very rapidly down to the subsoil. Thus, shower after shower may be quickly stored if the conditions are just right. After every rain, therefore, that tends to pack the surface, the field should be gone over with a light implement to restore the mulch and bottle up the moisture. When once the mulch is established, the moisture keeps moving down into the subsoil and is there held fast by capillarity. Rainfall after rainfall may thus be stored and kept so long as the surface is kept sealed with a proper mulch to prevent evaporation.

Weeds Must be Kept Down

As soon as the sun gets warm and the rains come, the weeds will start up. They come without bidding and need no cultivation to grow. They must be met and destroyed before they can take root. Various devices may be used for this purpose. When the weeds are young and tender, most any light harrow will do the business; but should they get a start, a disk harrow may be necessary to kill them. But weeds should never be allowed to get a start. They are not only the most inveterate drinkers in the world, but, while they are using up the precious moisture you are trying to store in the soil, they are also taking up a large percent of the plant food that has been liberated—and this you want to keep for your coming crop. An idea seems to prevail that weeds do not exhaust the fertility of the soil—that in some way they do the land good if you let them grow and plow them under. This is just like lifting yourself over the fence with your boot-straps. Keep every weed out of your summer tilled field. It will do you no good to keep the lid on to prevent evaporation if you allow a million little pumps to pull the moisture out through the lid. That lid must be tight—and you must see that it is kept tight.

When to Plow

The time to plow your summer tilled land is determined by conditions. In the northern spring wheat country plowing should be started in time to be finished before harvest begins. In the winter wheat belt of Nebraska and Kansas, the plowing

should be done in early July, and in Oklahoma and Texas in August. If the land is to be planted to either spring grain, or cultivated crops, the plowing may be delayed longer than if intended for autumn sown grain. But plowing should never be delayed a moment if it becomes necessary to keep the weeds down. Weeds must be kept down at all hazards, if it cannot be done with the harrow—you must plow.

Depth of Plowing

In case the land that has been summer tilled is old land, plow from six to seven inches deep. Experience has proven that it is unwise to plow to a greater depth than can be reached with a subsurface packer. And where the soil is fairly heavy—a clay or a clay loam—it is difficult to pack the plowed ground thoroughly to a greater depth than seven inches. And if you have held the season's moisture in the soil, this will be sufficiently deep, for your subsoil will be moist and will afford the growing plant an ideal root bed—firm and rich in plant food. A sandy soil may be plowed deeper, if plowed when moist. This is true also of the soil of the semi-arid west, known as volcanic ash.

Plowing Must be Packed

In mid-summer, when high temperatures prevail, evaporation from the surface is very rapid, therefore, the plowing on summer tilled land should be packed at once with a subsurface packer. The dryer the soil gets before packing, the less effective will be the work. There should be no delay. Where motor power is used, the packer should follow the plows in one operation. Where horse power is used the plowed field should be packed before leaving at noon and at night. Whether a harrow should follow the subsurface packer should be determined by conditions. Generally, the subsurface packer, while firming the under portion of the plowed ground leaves the surface in a pretty fair condition to resist evaporation, and a harrow may or may not improve it. A rain, however, that is sufficiently heavy to pack the surface should be immediately followed by the harrow to loosen up the surface just the same as before plowing.

Between Plowing and Seeding

Between the time of plowing summer tilled land and the time of seeding either to a fall or a spring crop, the same care must be exercised as before plowing to keep the weeds out and a satisfactory mulch on the surface. Remember that the

lid must be kept on or the moisture so carefully stored during the fore part of the season will escape. And right here, eternal vigilance is the price of success. It is the conservation of the water that you are after, and the longer you can hold it there and the more evenly balanced you can get the content of water and air in the soil, the greater will be your crop yields the coming year. Remember also, that while you are keeping your field bare and holding the capillary moisture up to the mulch, the summer heat and the microscopic organisms that inhabit the soil and flourish under these conditions are preparing the food for your next year's crop. Your field, though bare on the surface, is literally swarming with life beneath the mulch. You are not only storing up the sun's rays but the processes going on beneath the surface are unlocking the store rooms of the inner earth.

Summer Tilling New Ground

In summer tilling new ground the process varies somewhat. If the sod can be turned in the fall, well and good; if not, it must be turned as early as possible in the spring. Plow it while moist and to a depth of from three to three and one-half inches, turning the furrow slice completely over so that the grass may rest against the moist soil beneath. Follow the plow with a roller or a subsurface packer to crush the furrow slice firmly down, leaving the surface as level as possible. Here is where good plowing is essential. The furrows should be straight and free from kinks. If a surface roller is used, it should be hauled in the opposite direction to the progress of the plow. This will have a tendency to smooth out all sod kinks and crowd each furrow slice flat. Follow the roller, or the packer, with a disk harrow set to cut an inch or so into the inverted furrow slice. Never allow the disk to cut through. This will give you a mulch on the surface and fill all openings between the furrow slices. Sometimes it may be good form to follow the disk with a float, or smoothing harrow, but this is not usually good practice where the soil is likely to blow or drift when pulverized.

Why We Do This

The reasons for the above treatment are first—to rot the sod by pressing it against the moist subsurface; and, second—to form a mulch to prevent the evaporation of soil moisture. The reason why we break only three inches deep is because this is about the limit of the grass roots, and a three inch furrow will turn over and lie flat, leaving at the same time

enough soil exposed to the air to form an ideal mulch to protect the moisture in the soil beneath. At the same time this three inch coating will absorb and transmit to the under soil, which will be always moist, any ordinary rainfall during the season. Should weeds start up they must be handled just as they are handled on old ground. When a rain settles the mulch, it must be restored with a light harrowing, as on older ground. By midsummer, unless the season be excessively dry, the sod will have completely rotted and your field is ready to be plowed and prepared for either a fall or a spring crop. This plowing should be not more than five inches deep, and should be followed by the packer the same as in the treatment of old ground.

FIG. XV

Summer Tilled Field. Note the Soil Mulch and Absence of Weeds

CHAPTER 11

CONSERVATION OF SOIL MOISTURE

Do Crops Need Rain?

That crops can be grown and brought to maturity on moisture stored in the soil at the time of planting has been demonstrated by Professor Alway of the Agricultural College of Nebraska in a most interesting and conclusive manner. Six cylinders of galvanized iron were filled with soil as near as possible in its natural condition. Three cylinders contained soil from the eastern, and three from the western part of Nebraska. Water was added until seepage began, when it was allowed to drain away until only capillary water remained. The cylinders were then closed, except at the surface, and sprouted grains of spring wheat were planted in the moist soil and an inch of dry soil added to form a mulch to prevent evaporation. The cylinders were placed in a green-house, the atmosphere of which was kept as dry as possible. No more water was added. The wheat grew, developed and ripened normally. The first heads were ripe in 132 days after planting and the last in 143 days. The cylinders of soil from the semi-arid section of the state produced 37.8 grams of straw and twenty-nine heads containing 415 kernels which weighed 11.18 grams. The three cylinders of soil from the eastern or humid section of the state produced 11.2 grams of straw and thirteen heads, containing 114 kernels, weighing three grams.

This experiment demonstrated conclusively two things; first, that enough water can be stored in six feet of ordinary soil and held there by a surface mulch for the use of a crop from planting to maturity; second, that the soil from the semi-arid sections of the country is much richer in plant food and will produce greater yields (in this case three times the yield), than the soils of the humid sections, under identical or similar conditions.

Storage Capacity of Soils

The capacity of the soil for absorbing and retaining moisture depends on its physical structure—the finer the texture, the greater the surface area, and, consequently, the greater the water holding capacity. In this regard very little accurate data has been gathered for the reason that until within the last few years it was regarded as unessential. But from the tests that have been made, the average of field soils is about 1.5 inches of water per foot of soil. Now, if this ratio

will continue down ten feet, we can store twenty-five inches of rainfall, or the available moisture of two years precipitation on the semi-arid plains. The theory that in the average soils of the plains two or even three years rainfall may be stored in the soil seems to be proved by the universal experience of all the demonstrators and experimenters from the Saskatchewan river to the Rio Grande. Atkinson, of Montana, found that soil at a depth of nine feet, which contained 7.7 percent of capillary moisture in the fall, in the spring was found to contain 11.5 percent, and that after carrying it through the summer by careful methods of cultivation it still showed eleven percent. Widtsoe states that investigations in Utah show that of the water and snow, which fell during the winter, as high as ninety-five and a half percent was found stored in the first eight feet of the soil at the beginning of the growing season. Burr, of the North Platte, Nebraska, experiment station, has demonstrated that fully one-half of the spring and summer rainfall may be stored in the first six feet of soil. It may be regarded as clearly proven that from fifty to ninety percent of the rainfall in the semi-arid sections of the world may be stored in the soil and kept there for the use of the growing crops.

How Soil Moisture Is Held

It must be understood that water is held in the soil in the form of thin films around each particle, and not in the spaces. Therefore, it will be noticed that the soil grains where the very points of the little feeders come in contact with them show no water, the film of water having been so reduced by the drinking or sucking in of the solution by the very tip of the feeder. As the film is diminished around these grains the next soil grain gives off a percent of its moisture to even up, thus the movement of moisture goes on from one soil grain to the other, in an effort seemingly to keep up an even tension, or thickness of the films throughout the moist portion of the soil.

Not only does the moisture move laterally in the soil towards the points of these little feeders, but upward from below, as the demand of the plant increases, either from its increased size or from a greater evaporation from the leaf, caused by excessive heat. At such times these little feeders are taxed to their limit to gather in the moisture fast enough to prevent the wilting of the leaves. Under such condition the moisture in the upper layers becomes diminished and the supply must come from below.

How Soil Moisture Moves

Figure 16 represents a perpendicular cross-section of soil in various stages of saturation. Column A represents the condition of the soil immediately after a heavy rain. The moisture is represented by the dark part completely surrounding the soil grains, below is the dry soil with the interspaces filled with air, represented by the white. In column B the water has percolated down some distance, leaving the upper soil grains covered with a film of capillary water and the inter-spaces

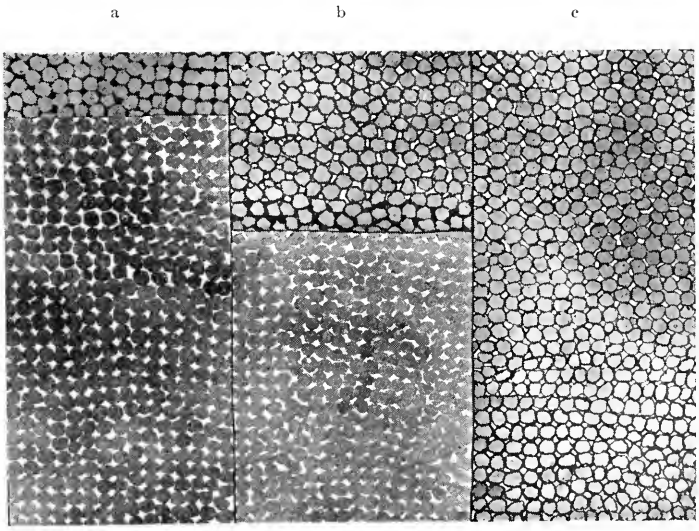


FIG. XVI

Getting Water Into the Soil

filled with air. In column C the entire soil section is carrying the highest limit of capillary moisture and the proper content of air—the ideal condition of the seed and root beds.

Assuming that the top of column C is exposed to the sun's rays and the wind, and that no loose soil mulch covers the surface to protect the moisture and to keep the top of the moist soil cool enough so no steam or vapor may be produced, under this exposed condition the sun will soon dry the surface

particles by transforming these films of water into steam, or vapor, thus causing the next soil grain below to reduce its film of water by the natural tendency to supply the one above, or the natural tendency of the upper grains to rob the lower grains as the moisture is lost by evaporation from the surface. This process, if not checked by cultivation, will go on until the entire capillary water has been drawn out of the soil.

Now we will assume that we have a loose mulch over the surface of column C, to a depth of about three inches. This would make it impossible for the moisture to move up beyond the firm point. If this mulch is cultivated sufficiently often to keep a crust from forming at the top of the firm soil, an ideal condition will exist, for the oxidizing and nitrifying processes to go on, which dissolves and liberates the plant food.

Something New

We already know how water is held in the soil—we are familiar with the laws of capillary action; we know that the plant takes its food from the soil in solution, and that whenever there is a scarcity of moisture, growth ceases. We have learned, too, how to catch and hold this moisture in the soil for the use of the plant; we know how to form and maintain a mulch to bottle up the stored rainfall; we know what the plant requires in the nature of a seed and root bed—all these things must be looked after in summer tilling a field. The primal object of summer tillage was to conserve moisture, to store two years precipitation in the ground for the benefit of one crop. This was the original idea. It is still a reason for summer tillage, but not the whole nor the most important reason—there is another and a greater reason, but it rests on the first like a building on its foundation. This other reason is the *liberation of plant food.*

Transpiration and Fertility

We have learned that the water in the soil is both food and drink for the plants; that if there is a lack of plant food in the soil for the water to dissolve there will be little growth; that when the soil solution is weak, the plant in trying to get enough food will use an enormous amount of water; that when the solution is stronger less water is used by the plant in production of a unit of dry matter. We have learned that there is a direct relation between fertility of the soil and the amount of water transpired by the growing crop—the richer the soil solution the less water used. We know that experimenters working in different parts of the world found that

summer tilling the soil produced the same effect on the amount of water required to produce a unit of dry matter, as the application of fertilizers. The conclusion is inevitable—summer tilling releases the plant food and renders it available for the growing crops. How is this brought about? It is brought about by the action of heat and sunlight when the moisture content of the soil is just right. It is brought about as a result of conditions favorable to bacterial action. Doubtless, each and all of these factors contribute to the result. The proper balance of air and water in the soil, together with the heat of summer produce conditions favorable to bacterial life, and this life is a necessary link in the process of rendering the inorganic substances of the soil available for the plant. It is possible, also, that the sunlight exerts a chemical effect on the soil substances favorable to the coming crops. Professor Montgomery found that the hotter the season the greater amount of water a plant will use to produce a unit of dry matter. He found that in 1910 it required two hundred-fifty pounds of water to produce one pound of dry matter (corn), but in 1911, a much hotter season, it required three hundred forty-five pounds under similar physical conditions, the temperature alone excepted. Now, why was this? Owing to the greatly increased evaporation from the leaf, by the excessive heat, the moisture at the top of the soil, was more quickly reduced, and the supply drawn from a lower strata of the soil, where the temperature was not sufficiently high to bring about adequate chemical action, consequently the moving of the water from this lower zone, carrying a much lower percent of soluble plant food, produced a like lower percent of growth. This conclusion is substantiated by figures of Professor Widtsoe, who found that where the transpiration from the plant was slower, the growth was greater from the same amount of water; thus, again indicating the necessity of the water being carried in the upper part of the soil, where the proper degree of heat obtained for a longer period, producing the high percent of soluble plant food as well as an increased percent of nitrates.

A Plausible Theory

Investigations along the lines of tillage, together with our knowledge of the conditions under which plant life thrives, all point to a theory that may account scientifically for the wonderful results obtained from summer tillage. Old principles that have played their part in the growth of plants since the cultivation of the Garden of Eden—principles that have never been fully understood nor regarded as of any importance, are now considered from an entirely new viewpoint.

This is the theory. When the capillary water is held in close contact with the soil particles of the root bed under the proper temperature, the soil at the same time being supplied with oxygen from a free circulation of atmospheric air, a chemical action takes place which liberates food by dissolving the inorganic elements of the soil and forming soil solutions. The longer the moisture under favorable conditions remains around the same particles of soil, the greater (to a certain extent) becomes the percent of soluble plant food in solution. When this capillary moisture, impregnated with an increased percent of plant food, is taken in by the minute rootlets or feeders—the mouths of the plants—and is digested and assimilated, growth is of necessity more rapid and vigorous, than when the moisture has remained a less period adjacent to the soil grains, for the simple reason that the dissolving elements have not had time to act. Therefore, it is quite reasonable to conclude that less actual water is required to grow a crop where the moisture has been held in the soil for a considerable length of time by summer tillage, than under ordinary conditions where the water is allowed to continuously escape through weeds or by direct evaporation. In other words, a greater growth and a larger crop yield may be obtained with the same amount of available water.

Demonstration at Sligo, Colorado

A most interesting demonstration tending to prove the above theory was made on the farm of Mr. S. G. Morgan near Sligo, Colorado, during the summer and fall of 1911. The record of the rainfall kept by Mr. Morgan for the year 1911, is as follows:

DATE AND AMOUNT OF PRECIPITATION AT SLIGO, COLORADO, 1911

April 29	.75 inches	April 30	.03 inches
May 10	.53 inches	May 19	.05 inches
May 28	.57 inches	June 15	.03 inches
May 29	.25 inches	June 21	.10 inches
June 16	.70 inches	July 2	.06 inches
July 13	1.53 inches	July 3	.07 inches
Aug. 9	.45 inches	July 16	.07 inches
Aug. 11	.25 inches	July 19	.20 inches
Sept. 2	1.19 inches	Aug. 5	.15 inches
Oct. 1	.25 inches	Oct. 5	.20 inches
		Am't available	.96 inches
Am't available	6.79 inches		6.79 inches
		Total	7.75 inches

In observing the above record it must be remembered that the precipitation at any one time must exceed one-fifth of an inch, or no benefits can be derived from the shower in the way of increased storage of water. It is also a known fact that a shower which is sufficient to moisten the mulch will reduce rather than increase the stored water, because the moistened surface tends to draw the moisture from below to the surface where it evaporates, a condition which is checked only by cultivation and the reformation of a mulch.

Out of the total precipitation of seven and three-quarter inches in twenty-one showers, we find ten showers of one-fifth inch or less, aggregating .96 of an inch, leaving about six and three-quarter inches from which a percent of each shower, eleven in number, could have been stored and retained in the soil. With this amount of rainfall, thirty inches of moist soil was found in the soil on November 20.

As there was practically no precipitation from October, 1910, to April 28, 1911, the records begin April 20. In the left hand column we give the dates and amount of rain out of which a percent could, with proper tillage, be stored in the soil, and in the right hand column the dates and amount of precipitation out of which practically no moisture could have been stored.

How the Work was Done

Mr. Morgan began early in the spring of 1911 to summer till thirty acres. Not being supplied with proper tools, he was obliged to reduce this to fifteen acres in order to keep the weeds out and retain the larger percent of all the moisture that fell. The remaining fifteen acres were cultivated thereafter, but the weeds were not all kept down, thus losing a considerable amount of moisture. On August 1, the whole thirty acres had just been plowed, packed and harrowed. The half that had been well handled was moist to a depth of twenty-six inches, while the part that had been less carefully handled showed about fifteen inches of moist soil, no part of which carried as high a percent of moisture as was carried by the soil of the other field—from right beneath the soil mulch down to the very last of the twenty-six inches.

Planted to Wheat

On the first and second of September the entire thirty acres were seeded to wheat, finishing at noon, the second. On the evening of the second, as noted in the table, one and one-fifth inches of rain fell; on the fourth the field was harrowed over. Now, note this fact, that with this amount of

precipitation and the harrowing the second day after the rain, it is fair to conclude that practically the same amount of moisture must have been available to the young wheat plants in both the well tilled field and the field where the moisture was practically lost through the growing weeds before plowing. Now, let us see what happened. Cut No. 17 shows four stools of wheat, two from the field kept clear of weeds and two from the other; A represents twenty-three well developed stalks, or stools, of wheat from one grain, while B, which grew in the field where weeds exhausted or utilized a large percent of the moisture during the summer, shows only six stools. The stooling of the single plants in the well cultivated field runs from seventeen to twenty-six, while the plants where the

a b

FIG. XVII

Results of the Morgan Demonstration

moisture was depleted in June and July, produced from three to seven stools from each grain. This shows very conclusively that the solution available at the roots of the plants in the well tilled field carried a much higher per cent of plant food than did the solution available in the other part of the field.

Demonstration at Holdrege

Similar results were obtained on the Burlington demonstration farm at Holdrege, Nebraska, in 1910. Figure number 18 shows two stools of wheat gathered November 18, 1910, from adjoining fields. Both fields were seeded about the tenth of September, one had been summer tilled, but the other had

grown a crop in 1910 and had then been plowed and planted to wheat. Fifteen days after seeding a very good rain fell, putting the two fields in the same condition so far as water content of the seed bed was concerned. The larger stool from the summer tilled field, containing sixty-three well developed stalks, is not an exceptional sample, but a fair average of the field. The smaller stool containing five stalks is also an average sample of the best part of the field treated in the ordinary manner.

While it is true that the seed and root bed in the summer tilled field was finer and firmer, which was more favorable to the rapid growth and development of roots, yet after the rain

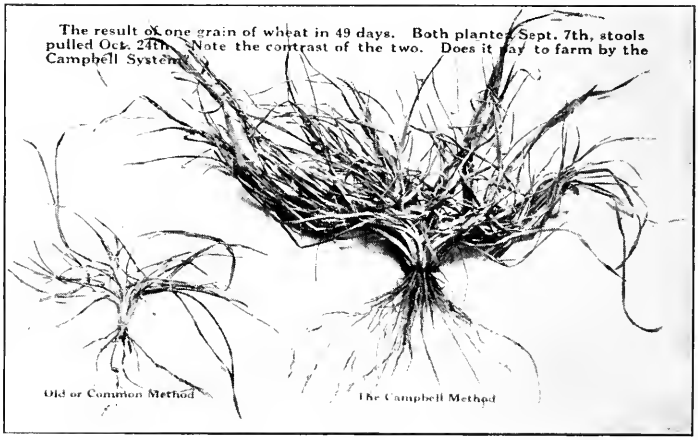

The result of one grain of wheat in 49 days. Both planted Sept. 7th, stools pulled Oct. 24th. Note the contrast of the two. Does it pay to farm by the Campbell System?
Old or Common Method
The Campbell Method

FIG. XVIII

Results of the Holdrege Demonstration

the last of September, the conditions in this respect would have been nearly alike in both fields because of the dissolving and settling effect of the rain on the late fitted field. It seems that the above facts from practical field results, bear out the conclusion that a very much larger growth of plants may be obtained from a given amount of water held or confined in the soil under proper conditions, than from a larger precipitation or irrigation under conditions where no attempt is made to control the water, which is allowed to move at will in its natural course.

While it is doubtless true that the evaporation from the first leaflets, as they made their appearance from the seed in each part of the field, were the same, yet in the well tilled field in which the higher percent of moisture had been steadily held in the soil through the hotter part of the season, there was a larger percent of available plant food which was, therefore, taken in by the little rootlets and carried to the plant in a richer form, to cause the greatly increased growth and stooling. As an illustration, suppose you feed a certain number of pigs clear milk from which the butter fat has been taken out and, to another similar number the same quantity of milk but to which is added corn meal. Which would be expected to make the greater growth?

Results From Summer Tillage

The results from summer tillage, when properly carried out, have been little less than phenomenal. The Nebraska substation at North Platte averaged forty-five bushels of wheat to the acre for five years in succession, running as high as sixty-seven bushels to the acre. On the Burlington demonstration farm at Holdrege, Nebraska, fifty-two bushels were produced, while one hundred thirty-two bushels of oats is the record of a summer tilled field in Alberta. In sections of the country subject to periodic drouths, summer tillage is an insurance against failure. Even where the rainfall is so low that alternate cropping is thought necessary, the yield obtained every other year is so much greater than can possibly be obtained under the practice of constant cropping that the farmer is far ahead of the game and with less work.

Objections to Summer Tillage

The objections that have been raised to this method of tillage are: First, that it tends to destroy the humus in the soil—burn it out, as it were; second, that it is too costly—the land must be left idle a part of the time and then it takes too much work to keep the weeds out and a mulch on the surface; third, that it causes the soil to drift (blow) wherever it is exposed to high winds, as it is in the semi-arid west where it is recommended by its advocates. Up to date, those holding these opinions have been unable to prove their objections to be well founded in practice. While there may be something in the theory, the objectionable features can be overcome.

The Humus Idea

The opponents of summer tillage claim that it will destroy the humus of the soil, and if persisted in long enough, put the

land completely out of business, so far as crop production is concerned. But they don't seem to have any demonstrated data on which to base their theory. On the other hand, Whitney, chief of the United States bureau of soils, says that humus is practically indestructible. In the meantime, the practice of summer tillage is producing bumper crops in good years and fair crops in drouthy years, with no apparent disastrous effect on the soil. Just in what way summer tillage should differ in its effect on the soil from the clean culture given corn, potatoes, or any other hoed crop, is not explained. There is little doubt, however, that in summer tillage, as in any other method of clean culture, it is necessary to replenish the soil with humus-making material if you want to keep the fertility of the soil up to the primal limit.

The Cost Objection

This objection seems too foolish to need attention, yet there are so many who balk right here that a word or two may do some good. We have already seen that as a general rule where the plan is to crop every alternate year, the yield is more than double the annual yield under the constant cropping system. Where then, is the loss from allowing the land to remain idle? There is none. On the contrary, there is a decided gain. But one seeding is necessary and but one harvest, and we all know it costs but little more to harvest a wheat crop that yields forty bushels to the acre than it does to harvest one that averages fifteen bushels. As to the item of cultivation, we must add the cost of three diskings and as many harrowings as the conditions make necessary. These will depend entirely upon the weed growth and the number of rains that come during the summer tilling season. The comparative cost must be figured out for each individual case, and it will differ with the seasons, the soil, and the time of the rainfall.

About the Drifting

Over a large part of the semi-arid west, especially in localities where there is a fine soil exposed to the sweep of the wind, if the surface be pulverized by surface rolling, or too much harrowing, it is likely to drift badly. This is a serious objection to clean culture of any kind, unless the mulch be kept in a cloddy condition, or the surface so ridged as to check the force of the wind. Here a dust mulch would be fatal to any field. If there is any moisture in the subsoil, and if the plowed soil be properly packed with a subsurface packer, a

mulch can be maintained that will not blow. This has been demonstrated beyond a doubt. It is the lifeless soil alone that drifts—the fine, powdery stuff that contains no moisture. If the moisture line be kept near the surface by packing, there will be sufficient hygroscopic moisture given up to the mulch to hold it intact.

The Ridge Theory

The ridge system of cultivation advocated by the Agricultural College of Kansas, will doubtless prevent drifting to a great extent. In this system the ground is thrown up into ridges with a lister—not plowed—with the idea that less rainfall will escape through the run-off than

FIG. XIX

Soil Listed to Conserve Moisture and Prevent Drifting

from level cultivation. When the ridges become dry after a rain, they are harrowed down, the surplus dirt falling in the furrows, thus covering with a dry mulch the wet soils. Care is taken to list the field as near as possible at right angles to the direction of the prevailing wind, so that the force of the moving air is broken every few feet and at least one-half of the surface is perfectly protected. This condition is maintained only in the fall and spring, when the winds are likely to do the most damage. Later in the season the ridged surface is worked down and the ridges split, if necessary, to conquer the weeds and harrowed back into a firm seed and root bed suitable for planting.

CHAPTER 12

PROPER PHYSICAL CONDITION OF THE SOIL

By proper physical condition of the soil we mean that condition of tilth which will produce the best possible results. We wish to prove to you that on the broad level prairies of the semi-arid belt nature has provided all the necessary elements to grow cereals, vegetables, forage and fruits in such quantities and of such quality as to satisfy the most critical. To accomplish this, however, the tiller of the soil must know what to do, when to do it, how to do it, and why he does it. We shall show you that it does not require a large expense nor a vast amount of labor to get good results, but it does require effort and intelligent knowledge with good judgment. Just as a valuable machine may be rendered powerless and useless by the wrong adjustment of a bolt or a nut, so in the mechanical preparation of the soil, success depends on doing the right thing at the right time and in the right manner. It will not do to guess at it. You could not put a machine together without knowing something about its parts and the principles on which it works. You cannot till the soil and get from it the best results in the nature of crops unless you know something of the simple principles of soil physics.

A vast deal of misleading matter has been published on the subject of soil physics and its relation to soil fertility. Many used to think, and some think even now that a chemical analysis of the soil will indicate just what crops can be raised and the probable yield. Nothing could be farther from the truth. Milton Whitney, chief of the United States Bureau of Soils, in United States Bulletin No. 22, says there is no apparent relation between the chemical composition of the soil as determined by the methods of soil analysis in use and the yield of crops, but that the chief factor determining the yield is the physical condition of the soil. It is our candid opinion, based on thirty years experience and observation, that the farmer need not bother himself with the chemical analysis of his soil until he has learned to secure the proper physical condition to assist nature to make available and utilize the needed elements of soil and air.

The potential soil fertility of the average high level prairie soil is all that can be desired and all that is needed is care in the conservation of the moisture that is applied by irrigation or that falls as rain and snow during the year.

In order to secure a condition to best conserve this moisture

the greatest care should be exercised in plowing, packing, and cultivating this soil when it is moist. When the soil is moist, as all observing farmers know, the soil grains separate readily, the soil crumbling in a mellow mass behind the plow or under the harrow. The real object of plowing is not to merely turn the soil over, but to pulverize it, and the more thoroughly this is done the better opportunity there is for the air and heat to exercise their full power in the liberation of plant food.

Nothing influences the water-holding capacity of the soil more than its physical condition. The deeper the soil is stirred and yet made fine and firm, the greater will be its capacity to receive and retain moisture. To plow deep and leave the under surface loose and lumpy is no insurance against drouth and our experience has shown that we never can tell when a dry spell will come.

Some would-be authorities, speaking from theory only, insist that our western soils must be loosened up deeply to let the water down. This is not essential providing the soil is moist a foot or so below the surface, and the surface is kept loose. As soon as the water comes in contact with the moist earth below it readily percolates down into the subsoil, gradually moistening it to a depth of from six to ten feet, depending on the amount of rainfall. In fact the soil that is moist down several feet will dry off more quickly at the surface than will a soil dry beneath. The reason is found in the more rapid percolation caused by the moist subsoil.

Amount of Water Content

A saturated soil will hold from twenty to thirty-two pounds to a cubic foot, depending on the kind and texture. The amount of this water content is least in sandy soils, large in loams, and reaches its maximum in soils with a high per cent of humus or organic matter.

Ordinary field and garden plants will not grow in a saturated soil, because under this condition practically all the air is excluded and the roots of plants must have air. The ideal soil condition is to be found when all gravitational water has been drained off, leaving only the capillary and hygroscopic moisture.

It is impossible to tell just what proportion of water gives the best results. It depends on the texture of the soil and the degree of tilth that is maintained. Intelligent observation and practice are the only means by which a farmer may know when he has obtained an ideal condition of the soil as to moisture.

CHAPTER 13

THE DISK HARROW—ITS USE AND ABUSE

No agricultural implement is more important to the western farmer than the disk harrow. Its use, however, has been more or less misunderstood—many have tried to make it do the work of the plow. Thousands of acres of wheat have been put in with the disk alone that have not turned the farmer a profit of a cent, and in many cases they have not recovered their seed. The great value of the disk harrow lies in its adaptability to the work of moisture conservation, the preparation of the soil for the encouragement of rapid percolation of the rain water, and the pulverizing of cloddy fields, thus securing a better physical condition of the soil. It has often been used in the place of the plow when it should have preceded the plow.

In handling a field for summer tillage, considering the cost of labor and results obtained, there is no tool that can take the place of the disk harrow. And while it is a tool that cannot be continuously employed by the orchardist, yet we do not see how a man can successfully handle an orchard without it. In combination with the plow in the preparation of a field for a crop the disk is most valuable—its action as a pulverizer both before and after the plow is complete.

To Be Used in the Spring and Fall

We most earnestly advise the use of the disk on previously cropped land as early in the spring as possible. No time should be lost after the soil has become sufficiently thawed and dry enough so that it will not stick to the disks. It is best to double disk by lapping one-half, the object being to break the surface to prevent evaporation and to present a rough surface to absorb the spring rains.

It is equally as important to use the disk in the fall as soon as the small grain or any other crop has been removed. It is advised whenever possible to follow the binder with a disk and not allow the soil to be exposed a single day to the rays of the sun after the crop is removed. It is difficult to emphasize the importance of this work sufficiently to impress the reader with its importance. Note the following reasons:

First: There is no time in the year when water held in the soil near the surface will bring about such satisfactory chemical changes by bacterial action as during the months of July, August and September. This bacterial action means

additional plant food for the next crop, but it will not take place unless the soil is moist and in a favorable mechanical condition.

Second: If there is any moisture in the subsoil, if a good mulch is prepared to prevent surface evaporation the moisture from below will rise and accumulate in the firm soil just below the mulch, so that if no more rains come and you want to begin your fall plowing your ground is in an ideal condition by reason of the accumulated moisture beneath the mulch.

Third: If you do not wish to plow in the fall this moisture can be carried over until spring, when if the season happens to be dry your soil can be plowed and planted and your seed will immediately germinate and grow while your neighbor who has neglected to disk his fields is worrying about dry weather.

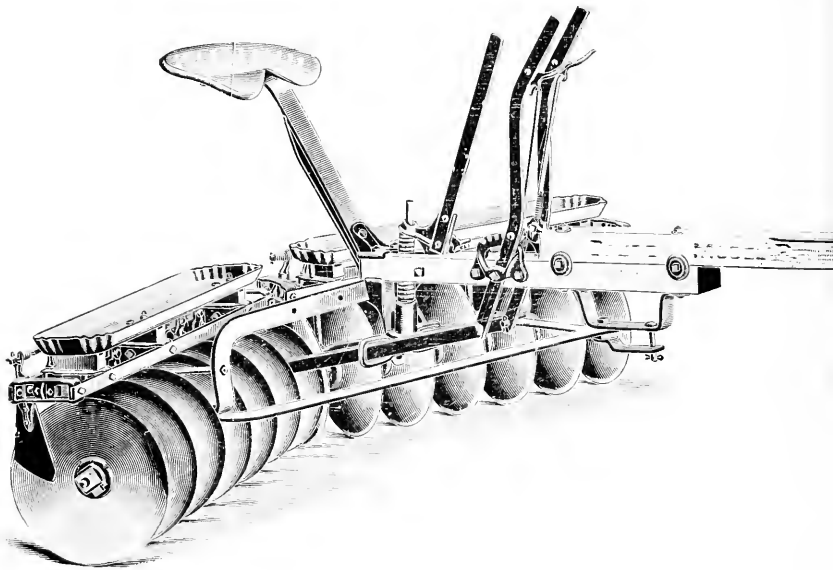
Fourth: In case you wish to sow fall wheat this early disking, by holding the moisture as shown above, may mean from ten to twenty bushels additional yield per acre. If, after disking, a heavy rain should come sufficient to pack the surface, the harrow should be immediately used to break the crust and loosen the surface, then by following the plow with the subsurface packer and the packer with an Acme harrow, you will have a fine, firm, moist seed bed, and your wheat will come up, stool, and grow rapidly.

Fifth: In most of our fields, especially those sown to small grain, are more or less weeds. These ripen and scatter their seeds ready for next year's growth. Fall disking covers these seeds and any scattered grain, causing them to germinate and grow to be killed by frost or subsequent harrowings. Disking after the crop is removed is one of the very best methods for eradicating weeds.

Size of the Disk

When the disk harrow first came into use fourteen inches was the common size, and this size we still prefer but the farmer, conceiving the idea that a larger disk is of lighter draft, has been demanding a larger disk. While it is doubtless true that the larger the disk the lighter the draft, it is also true that the smaller the disk the better the pulverizing action. The pulverizing effect of a sixteen inch disk is not as good as a fourteen inch, an eighteen inch is still worse, and a twenty inch disk we would not have on a farm. We have noticed twenty inch disks rolling over ground that was somewhat dry, slicing the soil and raising it up a little and then letting it fall back in large clods in practically the same position

it was in before the disk passed over it. The process simply made little crevices in the surface crust and actually increased the evaporation instead of decreasing it. A fourteen inch disk moving at the same rate would revolve faster, pulverize the surface, and completely reverse the soil. Don't buy a large disk, and get one with guard wheels to regulate the depth of cut. Double disk by lapping one-half. If you drive so that the side disk will just fill the furrows left by the center you will leave your field level. Keep your disks sharp and use as wide a disk as you have the power to draw—the more ground you can cover with one man the better.



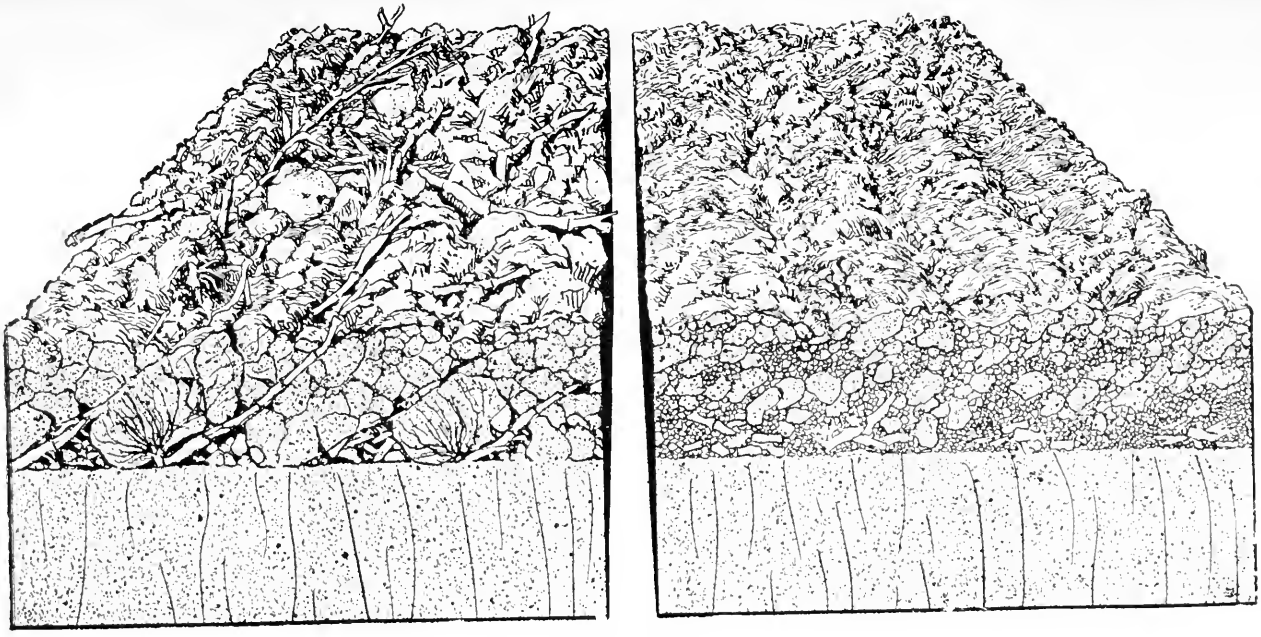


FIG. XX

Cornfield Plowed Without First Disking

Cornfield Prepared for the Plow by Disking

CHAPTER 14

SAVING WATER BY CULTIVATION

There are two vital points in regard to the successful growing of crops in the western country. The first is the importance of getting all the water possible into the ground, and, second, using every possible means to conserve or retain it there.

The importance of a little additional water is shown by the effect of snowdrifts that may form on the field from any cause. The increased amount of moisture that seems to find its way into the soil when the snow melts invariably makes itself apparent in the growing crop as soon as a dry period begins to affect the crop in the least. At these points the crop always holds out longer, sometimes carrying the crop over to another good rain, which results in maturing an unusually large yield on these places, while the balance of the field will not yield to exceed one-half or one-fourth the amount. Thus a gain in yield of wheat of probably ten bushels to the acre is the result of perhaps not over an inch of additional water that had percolated into the ground. The enormous evaporation from our fields under favorable conditions is not in the least comprehended by the average farmer because he has no means of readily testing and proving.

To be successful the farmer must grasp the full importance of doing all his work just at a time when the condition of the soil is best adapted. The idea that by plowing today we may get ten bushels of wheat to the acre, when if we plowed the ground four days later we would get fifteen bushels, or vice versa, seems rather ridiculous. While this statement and the figures used may be a little strong, yet it is a fact that the average yield of a field is frequently increased or decreased quite a percent by a few days variation in the time the work is done. This is especially true with reference to cultivation. We have in mind a case near Fairmont, Nebraska, where the phenomenal difference of fifteen to eighteen bushels per acre was made by cultivating a part of the field before a heavy rain of nearly five inches and the balance of it after this rain. The reason of this remarkable difference was simply what we have been dwelling upon, the result of retaining a large percent of moisture by the soil mulch produced by the cultivation after the rain, that was lost from the balance of the field by rapid evaporation. This occurred in July, and was the last

cultivation preparatory to what is called "laying by" the corn. The rain was a very heavy one.

The part of the field that was cultivated previous to the rain was left with the thick compacted crust made by the heavy fall of water, which resulted in dissolving the loosened soil and settling it very close, thus leaving the surface in the best possible condition for a rapid movement of moisture to the surface and evaporation. The portion not cultivated previous to the rain was gone over as soon after the rain as conditions would permit, thus producing a perfect protection to the moisture below, and bringing about the remarkable result referred to. While these cases cited seem extreme under similar circumstances you can look for similar results. When the reader begins to understand the direct effect of these conditions it will then be quite clear why a light crop was secured when a good crop might have been harvested.

Getting Water Down Into the Soil

The problem of getting the water down into the soil is one of equal importance with that of conserving the moisture, which is now quite commonly understood and accomplished by the use of the soil mulch or surface cultivation. In Figure 21 we have attempted to illustrate the percolation of water, or the getting of water down into the soil. We have divided this figure into three sections, numbering them 1, 2, and 3, from left to right, then dividing these sections into lateral strata A, B, C, and D. In section No. 1, A represents the soil mulch, a stratum of light, loose, and dry soil; B represents a stratum of thoroughly pulverized and firm soil, meaning the portion that is cut by the plow; C represents about eight inches of the subsoil into which water has percolated; and D represents the portion of subsoil still below that is yet dry. In section 2 we find the mulch has been compacted by a heavy fall of rain. This mulch in its loose condition takes in the water, and as soon as the water reaches the moist soil found in strata B and C, it immediately percolates down below, and is shown by the darker portion of soil in the upper part of stratum D. Here the water has come in contact with dry soil, which resists percolation. Slowly and steadily by gravity the water finds its way down the columns of soil, which by the way, throughout the entire semi-arid belt, are almost invariably found in a perpendicular position. In section 3 we have again reproduced the soil mulch by cultivation to stop the evaporation or loss of water from the surface, and we find the moisture below has percolated on down until the water is

all distributed, each little particle taking on its film of water to a given thickness which it seems to steadily hold onto while the balance of the free water finds its way on down until it is all distributed. The next rain will result the same as is shown in section 2, only we have six, eight, or twelve inches more moist soil for it to pass through before reaching the dry soil.

Effect of a Moist Soil

An illustration will make this more clear. In setting out our cabbage or tomato plants in the spring of the year when the surface is dry and fine, we usually water them. In our

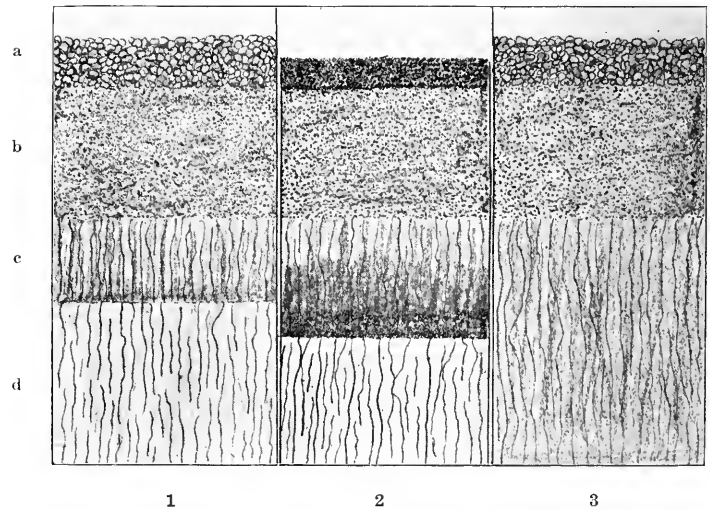


FIG. XXI

Showing Effect of Percolation of Soil Moisture

first application of water to this dry surface we notice the water does not seem to percolate, but for a little time remains dormant on the surface. After a little it finds its way down through the dry particles by force of gravity, leaving each particle it passes covered with a thin film of water. Then we apply a second application of water while the surface is still moist and we notice the water immediately disappears. The reason of non-percolation of the first application is because of the resistance of the dry particles to moisture, or repulsion for water. The quick movement of the second application of

water into the ground is the result of the attraction of water for water.

This illustrates how easy it is to get moisture into the soil by keeping the surface constantly loose and open, so that as the rain falls it soon works its way through the larger pores until it reaches the moist particles in the firm soil when it immediately percolates on down below. Here again nature has done a great deal for the semi-arid belt. The peculiar formation and size of the usual particle of soil is very favorable for percolation; also for its return upward by capillary attraction to feed the plant during our long dry seasons. The movement of this moisture upwards cannot be better illustrated than by the movement of the oil up the lamp wick. No matter how deep the bowl of the lamp is, if the wick reaches the bottom the blaze continues to burn, not only until the oil is all taken from the lamp but until the wick has become quite dry. The same rule or fact applies to the growing plant. So long as there is plenty of moisture below it will move up through the soil to the plant, keeping it in a perfectly healthy condition until the moisture is not only exhausted for several feet down, but the soil near the plant has become apparently quite dry. Then the plant begins to fade and wither.

The deeper you can store the moisture the greater are your chances of securing a large crop.

A piece of ground that is moist for two or three feet down will take in the water of a heavy rain much quicker than ground that is dry. Here again is illustrated what moisture will do for us when we understand its ways.

ANCIENT SAXON PLOW.

CHAPTER 15

CORN

Preparation of the Soil

In the eastern states, among the hills of New York and New England, a large amount of time is given to the preparation of the soil. Experience has taught them that without this, crops are light. Barnyard manure is used freely, and two, three, or four dollars worth of fertilizing per acre is not uncommonly necessary in order to secure good crops. Professor Bailey of Cornell University, Ithaca, New York, has well said that no after cultivation can make amends for a poor job of preparation. This applies just as much to the semi-arid belt as it does to the eastern sections of the country. In Illinois the soil is more fertile and rain usually ample, so that no fertilizers are required and when the rains are ample and timely two or three ordinary cultivations produce a good crop of corn. But even there they are beginning to learn the value of conserving the water by more frequent cultivation, because of dry periods that are liable to come at any time. In the semi-arid belt more attention must be given to the preparation of the ground. We cannot depend upon heavy rains to aid us in dissolving and settling our soil, consequently we must give close attention to every part of the work. The first thing in order is the early disking which should be a double disking in order to thoroughly pulverize the surface, bearing in mind that every act must be to store and provide the greatest possible amount of water in the soil. Early disking covers the two important points previously referred to, that of preventing the evaporation and opening up the surface to receive the later rains. This done, we simply wait for the proper time of further preparation and planting, always being in readiness, however, to loosen the surface at any time should we get a rain of any magnitude. There is some diversity of opinion as to whether the check-rower or lister is preferable, more particularly in the lower altitudes. We favor the lister in the higher altitudes, or in the northern sections where the nights are cooler which results in heavier stooling or suckering. These additional shoots are very detrimental to the corn crop, especially so should we have a dry season, but for the more humid sections we still favor the check-row planting especially on rolling land.

The Lister

The lister has one advantage that is especially desirable. By filling the furrows about the time the suckers begin to show they are covered up completely. Another advantage is that of getting the roots deeper into the ground. The higher the altitude and the drier the atmosphere, the deeper is it necessary to cultivate in order to produce a deeper mulch to prevent evaporation. In using the lister on ground where the moisture has been carefully preserved by disking and harrowing in the early spring it is quite important to follow the lister with some tool to thoroughly pulverize the moist soil that is thrown up as such soil soon becomes dry and very hard and is afterwards hard to manage.

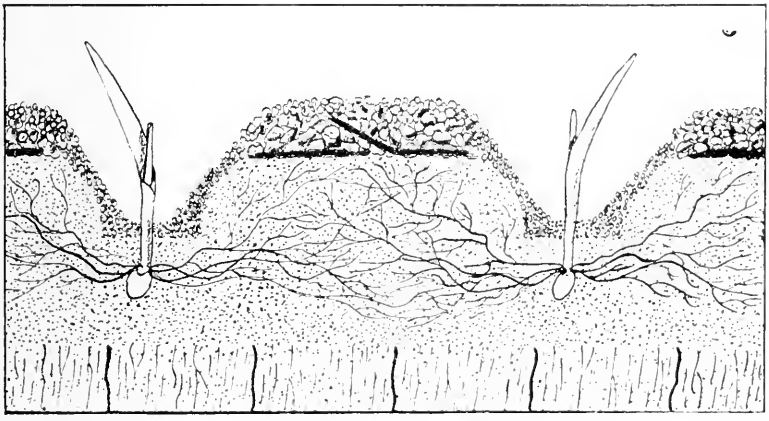


FIG. XXII

Corn Planted With a Lister

The best tool for this purpose is the weeder; the long flexible teeth lap down on the side of the furrow or ridge as thrown up between the rows and quite completely pulverize the large clods that are thrown up by the lister, leaving a perfect circle with a nice fine mulch over the entire surface. This puts your ground in magnificent shape, especially in the sand loam soils of the semi-arid belt, so that you can continue the use of the weeder by going lengthways of the ridges and completely destroying the weeds before they assume any size. Keep your mulch in perfect condition to prevent evaporation by going over the ground after each rain as in the cultivation

of other crops, watching the condition very closely in order that you may catch the ground just when slightly moist, before the crust has begun to form. This does away with the weed cutting idea.

In growing listed corn we do not believe in very deep listing, but in thorough cultivation from early spring until the crop is put in, then consider fully that ample moisture and air must be in the soil and that weeds growing in a corn field live on your best corn.

Check Row Planting

In planting with the check row planter it is important to plow the ground as early as possible. Here, again, the early disking comes in with its all important results to prevent the evaporation, holding your ground in perfect condition for rapid percolation of the later rains. This is advisable because you can get onto your ground with the disk when it would be too wet at a proper depth to plow. Then, again, you can cover the field quicker if you have a broad gauged disk than with the plow. It also enables you to get your soil in much better physical condition than would be possible if the ground were allowed to dry out. The plowing should be followed up soon after, but remember this point—if you have been particularly persistent in preventing this evaporation by the disking, your ground is in perfect condition to plow, even though you have considerable dry weather later on in the spring. The soil will roll up in a moist condition, and is susceptible to the best results with the packer or any other tool. Follow the plow closely with the packer, at least every noon and night.

There are few places where the subsurface packer turns the profit it will in following the plow in preparing a field for corn. In an experiment on the Burlington farm in Phelps county, Nebraska, in 1904, where a strip of land in a field being prepared for corn was left without packing, the following facts were observed: Germination was four or five days slower; the stand of corn much less uniform and the final yield per acre fully fifteen bushels less.

After your ground is turned over and the necessary work done to pulverize the surface, watch closely the condition. Whenever any rain comes, even though it only wets through the mulch or loose soil on top, it is necessary to immediately stir it to dry it out.

The growth of roots as shown under the head of root development is also interesting. Do not put in too much

seed. There are unquestionably many instances where very light crops of corn have been secured from too much seed. Had there been half as many stalks growing there would have probably been two or three times as much corn. We have frequently heard the remark: "If you don't put in the seed you can't get the crop," indicating the crop was gauged by the quantity of seed. This is another mistake and is beginning to be more generally understood. The strongest evidence along this line is found in some experimental work which we conducted in 1897, where eight ears of corn were

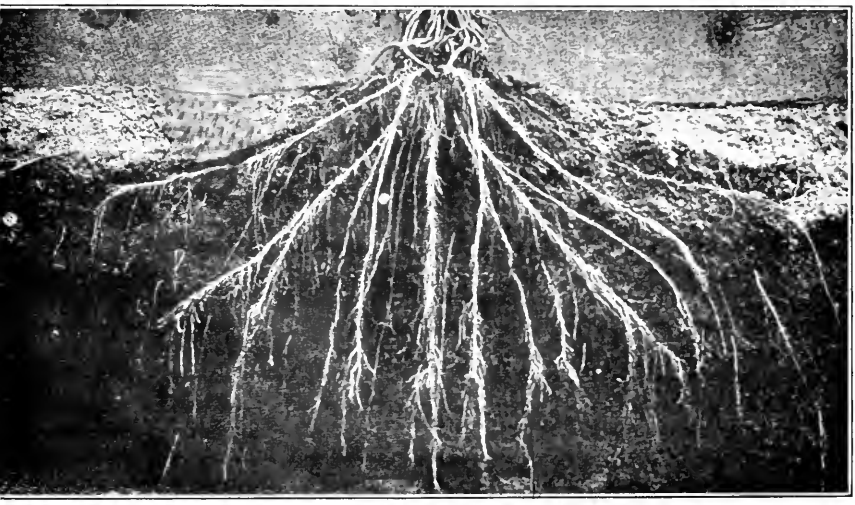


FIG. XXIII

Showing the Extensive Root Development of a Hill of Corn

raised from one single kernel. Seven of these were well developed ears, the eighth having corn about half the length of the cob, the upper and lower ends being bare of corn.

Amount of Seed Necessary

One fact not generally known is that every healthy corn stalk starts from five to ten ears. Now the development of these ears depends entirely upon the physical condition of the soil and the supply of available soil moisture, air, and plant food. It is true there are conditions that might exist where more corn might possibly be got from two, three, or four stalks in a hill than one. There would be rare cases

where by extreme heat the demands upon the supply of moisture and plant food might suddenly destroy the vitality of all the ears that were started on the corn except the top one; then a sudden and liberal rain replenishing the soil about the roots with the necessary moisture would immediately increase the supply of plant food and push to completion the single ears left on each stalk, when we would have two, three, or four ears to the hill as against one ear if we had but one stalk. But should the dry period continue longer without any rain we might lose all the ears because the demand for moisture to supply the growth and development of two, three, or four stalks would be just that much greater than for one stalk, consequently the one stalk could endure the drouth longer without suffering, and probably reach the next rain when ample moisture would mature one or two good ears, as against none at all with a larger number of stalks.

* * * * *

Things to Remember:

Plenty of water in the soil makes plenty of corn.

No after cultivation can make amends for a poor job of preparing the soil for a crop.

The deeper you can get the water stored down in the ground before planting time the surer you are to get a big crop.

Cultivate your corn at least once after the last rain. If you don't need the water for this crop you may the next.

Don't get the shallow idea too strongly fixed. Two and a half to three inches of fine loose soil is about the best condition.

Watch the first approach of spring and as soon as you can get into the field with your disk, go over your ground intended for corn. Nothing can pay better.

There is no work done, cost considered, that seems to go farther toward increasing the yield of corn than that of early double-disking. This is also quite true with reference to all other crops.

Never allow a crust to form under the mulch any more than you would on the surface. It will get there if you don't watch closely during times of extreme heat in long dry periods. Don't let weeds grow. Every weed means less corn.

CHAPTER 16

WHEAT

Spring Wheat

In discussing the growing of wheat it seems almost necessary to divide it into two headings—winter and spring.

Spring wheat in the northern sections and in Canada has become a very important crop. In preparing ground for this crop little attention has been given in the past to the all important question of storing and conserving the rain water. It has been simply a question of plowing at any time when the farmer was ready to plow, the seeding and harrowing likewise, without reference to the condition of the soil or the storage of water. In the more arid portions of the wheat belt in the northwest there is no question that summer tillage, commonly termed summer fallow, would be found exceedingly profitable. While we have thoroughly discussed this question in another chapter referring especially to summer tillage, yet its work is of such great importance and the additional expense so little compared to results that we cannot resist a repetition.

If the work is properly done the returns are large. Begin first in the early spring, just as soon as the frost is out of the ground and the soil sufficiently dry to permit of disking without the soil adhering to the disk; lap half so as to thoroughly pulverize the surface, thus putting your ground in condition to prevent evaporation, as well as to admit of the rapid percolation of the early rains and you will be surprised at results. Keep the surface harrowed or loosened by the use of some tool to the depth of at least two inches, plowing in June or July, the time when other work is least pressing, to a depth of six or seven inches, following the plow closely with the subsurface packer and let the packer be followed closely with the harrow, keeping in mind that all-important point of working the soil when it is in the best condition to most thoroughly pulverize, continuing this surface cultivation after the plowing through the entire season. In this work again the Acme harrow is most desirable because each time over it brings the soil from below up and to a large extent turns the soil from the extreme surface to the bottom of the portion stirred by the Acme. In this kind of work in the northwest, as well as in any portion of the semi-arid belt, it is very important to do this surface cultivating, whether it be with the common harrow or the Acme harrow, spring tooth or disk, at a time when the soil is in the best possible condition; that is, simply moist, not dry or wet. Then you have a fine, even soil mulch

composed of minute lumps, a condition you cannot get if the soil is dry or wet. It is when soil is in this condition that the particles seem most readily to separate, not simply into dust, but into minute lumps made from slightly moist soil which when dry will never blow.

Having had twenty-five years experience in the northwest I am well aware of this blowing difficulty on the lighter soils, which can be entirely prevented by care with reference to the condition of the soil as above stated. It is very desirable in following this plan to keep the weeds entirely clean from the field. Don't for a moment encourage the idea that weeds are valuable to turn under, for there is so little value to them that it is not worthy of consideration, but the water drawn out of the soil by these weeds while growing is far more valuable to the coming crop. Watch it carefully. In the springtime try to catch this ground as early as possible with the harrow, Acme preferred, and put in your seed, not to exceed one-half bushel to the acre. This quantity is ample.

If you will give close attention to this point you will simply be astonished at the results obtained. When a crop has been taken off, get on this ground as quickly as possible with the disk harrow. Double disking is exceedingly valuable. The small size disk, fourteen or fifteen inch, set at a good angle will quite thoroughly pulverize the ground, but with the larger disk it is impossible to get a good condition without double disking. Remember that the object is to thoroughly pulverize the surface two or three inches, to not only prevent the loss of any moisture we may have below, but to have the ground in the best possible condition on the surface for the rapid percolation, or getting of the rain waters down into the soil. Lose no time after any rain in again loosening the surface, especially upon ground that you may have already plowed. After the disking, plow and pack and harrow, as stated with reference to summer tillage. Should you get any heavy rains late in the fall lose no time in loosening the surface to save the water, for you may need it the following year.

When spring time comes get over your ground as quickly as possible with the harrow, aiming to do this before the surface gets dry, put in your seed, not too thick, and await its development when it reaches the stooling point which it will do early in the season if your ground is in condition. At this point of growth, that is when the wheat is beginning to stool, or tiller, go over your ground with a long-toothed weeder. This will loosen the surface and destroy the weeds. The checking of evaporation by this cultivation will

urge on your wheat when it will soon cover the ground, then the danger of evaporation is much less. The rich prairie soils of the Dakotas, Minnesota, and other sections of the northwest should produce thirty to forty bushels of spring wheat instead of five to twenty, and will if the soil is properly handled.

Don't think that you can get this rapid growth and early heavy stooling of the wheat unless your ground is thoroughly fined and firmed and you have held the moisture below, forming a seed bed in which there will be a rapid development of strong roots which is the direct result of prolific stooling. The use of the weeder, or harrow, on wheat after it has begun to stool, or is three or four inches high, when your ground is loose and porous where the roots should grow, is not always a safe proposition. The root development is so light that much of the wheat may be easily pulled up and destroyed.

Winter Wheat

Winter wheat is a little different proposition from the spring wheat. Here again we believe when the farmer in the winter wheat belt has learned the value of summer culture and how it will not only greatly increase the average yield, but make a failure, so far as drouth is concerned, an impossibility, a large acreage will be thus treated. Our experience and the experience of thousands of others during the last twenty years is certainly evidence that our ideas drawn from years of experience and observation are something more than theory. They at least carry very strong evidence as to the value of this class of work where by thorough and careful preparing of the soil, having plowed about seven inches deep, following our plow closely with the subsurface packer, and the packer with the Acme harrow, going over our fields immediately after the heavy rains, or as soon as the soil was sufficiently dry to permit it, we had formed a fine, firm and very moist seed bed. Under these conditions twelve quarts of seed was found to be ample. Its germination was quick and the rapid development of roots brought about by the very favorable physical condition of the soil caused liberal stooling and in thirty days after seeding the ground was nearly or quite covered with the wheat.

Disking after the Binder

The immediate disking after the winter wheat crop is removed is of very great importance; as we have repeatedly said, it is of two-fold value as it prevents the loss by evapora-

tion of moisture in the soil and puts the surface in the best possible condition for the rapid percolation of later rain waters. The plowing may be done a little later, and to get the best results a good depth of plowing is necessary, and then the plow should be followed with the subsurface packer. Mark you, we are after a condition that will not only enable us to get the best possible results, but prevent the serious damage by drouth and assure good crops annually. A fine, firm seed bed, or root bed, has many advantages over the coarse, loose one.

In the first place, only one-third of the seed usually sown is necessary. In the next place, the growth and development of the plant is much more rapid and will soon cover the surface. In the third place, the development of roots is much greater, we are able to draw moisture and plant food from a much larger percentage of the soil, and, last but not least, we have a condition of soil that will hold a much greater percent of moisture as well as one having a greater power of capillary attraction, enabling us to keep up the supply of moisture which we draw from below, where by careful work, much of the rain waters are stored that under ordinary conditions would have been lost by evaporation or run-off.

The plan of raising wheat by plowing every third or fourth year and simply using the disk for two or three consecutive years, or even reducing the cost still further of putting in the crop by using a disk drill, is altogether wrong. It is not at all surprising that many farmers resort to this instead of simply plowing three or four inches deep, leaving the plowing without even harrowing, lying up light and loose and full of cavities, a condition that could scarcely produce anything but weeds in an ordinarily dry season; yet it seems like folly for a man to so prepare his ground that nothing but a very favorable season could give him even a fair crop, when with a little additional work he is able to materially increase the yield as well as guard against a failure. No farmer should be content to call twenty bushels of wheat a good crop. Our prairies of the semi-arid belt are capable of producing forty and fifty bushels with the conditions nature has provided.

CHAPTER 17

IRRIGATION

Economical Use of Water

It would hardly be proper to close this book without a word on irrigation, especially considering the fact that some seem to have the idea that the Campbell system is antagonistic to irrigation and that the promotion of this work generally would retard the development of irrigation enterprises, but this is far from the truth. We have millions of acres of the most fertile lands, level and easy of cultivation, that can never be irrigated without unwarranted expense, which receive ample rainfall annually to produce fine and profitable crops if these waters are properly stored and utilized. Then there are millions more of choice acres with sufficient rainfall to make irrigation impracticable where the present average yield is not to exceed one-third what it might be if the general principles outlined in this book were fully understood and practiced by the farmer.

Then again we have millions of acres for which irrigation is necessary to secure profitable returns, but the available water is not sufficient when so wastefully used as is the case today along most of our ditches. Most men seem to think when they have the ditch completed, and water in unlimited quantities, they are in position to grow large crops. They are, but do they? Not as a rule, and the only reason why they do not is they do not handle the soil correctly. The average farmer in Illinois, Iowa, and the other similar states does not obtain to exceed one-half the yield he might from his fields were he more familiar with the scientific principles of soil culture; or, in other words, if he better understood the relation of the soil and moisture to plant growth. The same can be said of the average irrigator. The same great and vital question arises in irrigation—the utility of air and water.

Campbell System Applies

The fundamental principle upon which the success of the Campbell system is based is the economical use of water, it matters not from whence it comes, whether direct from the clouds or from flowing streams, ditches, reservoirs, or wells. The first and very important thing to do is to get a supply of water stored in the soil to feed, nourish, and mature the crop in a period of dry weather; the second and almost equally important

requisite is the seed and root bed, so vital in the success of this system, all of which is necessary in growing crops by artificial application of water required by irrigation. And, third, but by no means least, is that very important question of the control and utility of air, a question very little understood and much less appreciated by the average irrigator as well as the average farmer generally. It is true that a man may get a better crop with plenty of water to turn loose at will upon a piece of ground poorly fitted than he could with the same reckless fitting and be obliged to depend upon replenishing his soil with moisture from the heavens, but this is not the question today with the progressive farmer. It is how can we get the greatest results from our soil, labor and expense. In irrigation water usually means money. There are few irrigation ditches today that carry enough water through the season to irrigate all the land that might be reached with water from the ditch. There are many fields that are made to suffer that are under the ditch and crops made light that if the principles involved in this book were understood and applied precisely as we outline them, larger yields might be realized, and more acres covered with the same amount of water. And this will be realized when the irrigator better understands the nature of plants and just what physical condition is best for the support of healthy roots and how they gather plant foods. Due consideration must be given to the roots of the plant and their necessary supply in proper quantities, not only of water, but of air also. Too much water at times is just as detrimental as too little water. Too much air, as well as too little air in the soil is also a serious hindrance to the growth of the plant. Only the proper quantity of both can bring best results. A clear conception of how water moves in the soil is just as important to the irrigator as to the man who depends solely upon the rainfall.

The ideal condition for the most healthful and successful growth of all cultivated crops is a good depth of root bed made thoroughly fine and firm. There is little danger in getting the average sand loam soils so common in the arid and semi-arid sections too firm while some of our heavy clay soils if not properly handled might become too closely compacted; but this kind of soil is not at all common. Previous to the thorough fitting of the seed and root bed see to it that ample moisture is stored below where nature can do her part by bringing it up to the roots of the growing plants by capillary attraction, then keep your surface always cultivated in such

a manner as to provide as near as possible a fine, loose mulch of soil (not dust), stirring it often enough to keep the moisture up to the top of the firm soil just beneath the mulch. The moment the top of this firm soil becomes in the least dry there is immediately a process of depositing of salts and other matter between these particles of soil, closing the pores and consequently diminishing the quantity of air that should freely pass through this soil to the roots. This condition not only points to the fact that you are allowing the air to be shut out but that you are losing the moisture by evaporation from the soil.

FIG. XXIV

Furrow Irrigation. An Economical Method

CHAPTER 18
CROP ROTATION

We advocate crop rotation as far as it can be carried out. There is an advantage in rotation in a three years plan in the semi-arid belt. The plan we suggest is not absolute but one that can be safely carried out. The same plan also may apply in the winter wheat section of Canada. However, with a rainfall that can be reasonably relied upon for time and quantity of twenty inches, we believe with summer tilling one year, cropping the next two and then summer tilling again, that by close observation to details in conserving moisture the entire year through there is little or no question of good crops being grown annually for a number of years, but no one should bank on this until he has thoroughly mastered the question of summer culture and the necessary physical condition of the soil.

First Year

Begin by summer tilling one season. Go at it with a will and see to it that you store and conserve the entire season's rainfall from early spring to autumn. Keep out the weeds. Sow your fall wheat, if in central or southern Nebraska, first to tenth of September; if in northern to central Kansas, sow from the tenth to the twentieth of September, using not over thirty pounds of seed. If your work has been well done and the soil is in good physical condition do not sow more than twenty pounds of seed per acre. Remember that our dates for seeding and quantity of seed are based on thorough preparing, under which conditions it will be found that the fall growth will be ideal.

Second Year

The second year we harvest our wheat crop in Kansas in June, in Nebraska the last of June or early July. From the harvesting of this crop to the close of the season we prepare for the crop to be grown the third year as follows:

If possible, follow the harvester with the disk. If you cannot do this, go over the field with the disk just as soon as the crop is cut. Whatever you do, double disk as elsewhere explained. The quicker and more thorough you do this the better will be your crop the following year. After double disking, continue just the same as if summer tilling. Keep the weeds down at all hazards and get over the ground with some tool as quickly as conditions will permit after each rain. Plow as soon as the soil is in condition, following all work after plowing the same as for summer culture and you

are ready for a crop of corn the following spring, or oats if you prefer, but corn is preferable, and if well tended you can bank on a crop.

Two Crops in Three Years

This plan, if faithfully and carefully carried out in sections similar to western Kansas and Nebraska will result in two good crops out of three years of a proportionate magnitude to the crops reported elsewhere by the every other year plan by summer culture one year and cropping the next. In a series of ten years average crops will be produced that will compare favorably with the average crops grown in Iowa or Illinois under the present general methods in the same number of years.

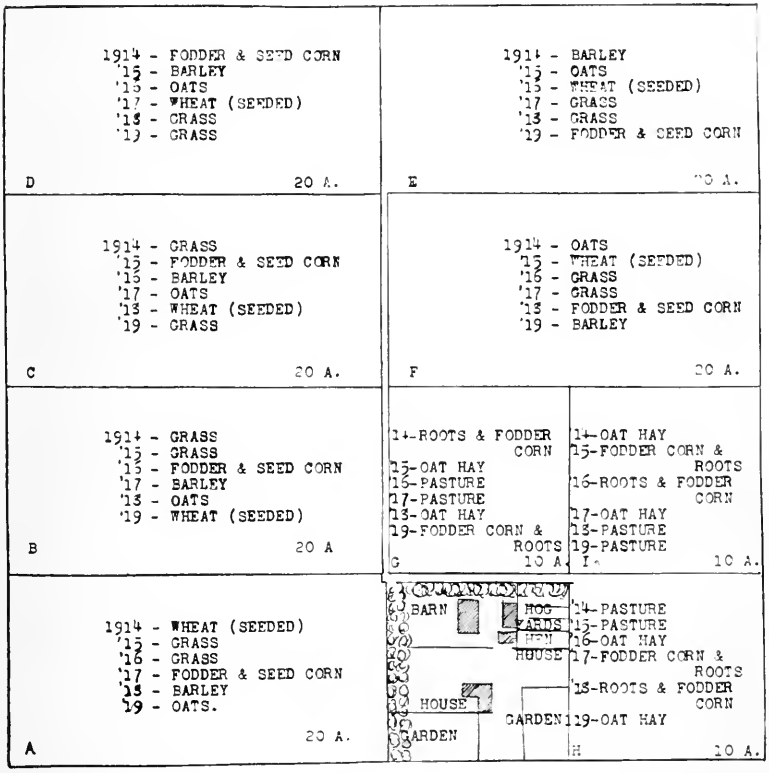


FIG. XXV

A Well Arranged Farm Showing a Six Year Rotation

CHAPTER 19

NECESSARY FARM TOOLS

We have been asked many times for a list of the implements we consider best adapted to general farming on the prairies of the great semi-arid belt. This, we realize, is a delicate subject on which to give advice, therefore we simply give a list of such tools as we bought for our own farms. For ordinary sized farms we favor four horse tools, or larger, as far as it is possible, for to decrease the cost of production adds profit. When one man can turn over two fourteen-inch furrows or twenty-eight inches by driving four horses instead of sixteen inches by driving three horses, he is not only decreasing the cost of plowing over thirty percent, but is getting a field plowed in six days that would take ten days with the sixteen inch plow. This is an advantage in many ways, and what is true of plowing is proportionately true of all other farm work.

The following tools make a very complete outfit for four good heavy work horses and with these horses and tools 80 to 100 acres can be handled on the high level prairies of the semi-arid belt where the soils are of the usual sand-loam formation.

List of Tools

One gang plow, two fourteen-inch bottoms.
One four horse disk harrow.
One four horse Acme harrow.
One spike-toothed harrow.
One four horse subsurface packer.
One two row cultivator.
One one horse cultivator.
One Eureka weeder and mulcher.

In addition to these tools come such planters, drills and harvesters as shall be needed for the crops the farmer may wish to raise.

The list of tools is such as has been found most desirable for securing the best possible physical conditions of the soil at the least expense.

There is no tool among these mentioned when it comes to farming in the semi-arid belt under conditions where a dry period is liable to come at any time during the growth of the plant, that will do as much to increase the yield and certainty of crops as the subsurface packer.

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